THE NATIONAL

SHIPBUILDING

RESEARCH PROGRAM

EVALUATION OF THE

BENEFITS OF HSLA STEELS

Cooperative Effort by:
Maritime Administration of the U.S. Department of Transportation
Bethlehem Steel Corp., Marine Division, Newport News Shipbuilding and
Drydock Co., and Ingalls Shipbuilding, Inc.

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FOREWORD

The need for ships and oil well drilling equipment to operate in the extremes of polar climates has given emphasis to the need for high toughness, weldable steels. Important weight savings become available where designs currently use normalized, medium strength, low alloy steels. Significant cost savings become available if the new steels permit higher production rate welding in heavy fabrication.

One of the objectives of this study was to procure plate sections of ASTM A710 steel in yield strength levels of 80 KSI (80,000 pounds per square inch) and also ASTM A710 modified in chemistry to yield strengths of 100 KS I minimum yields. Plates to over 5 inch thick in both strength levels were procured and welding was performed to evaluate producibility for shipbuilding and marine structures. Effects of high heat welding on heat affected zones (HAZ) toughness was of primary interest.

Conventionally used quenched and tempered steels, such as HY80 and HY1OO, require preheat and interpass temperature controls during welding of plates thicker than 1/2 inch to prevent cracking and loss of toughness in weld metal and in base metal HAZ. The problem is more severe with greater thickness in welded structures. High strength low alloy steel with added copper for precipitation strengthening (aging) and added nickel for toughness, has been developed and is available in plates as ASTM A710 in several grades. This material has excellent low temperature toughness and unique resistance to HAZ embrittlement and hydrogen-induced cracking, even with little or no preheat for welding.

With minor variations in chemistry, ASTM A710 has been qualified and approved for use in U.S. Navy hull structures in thicknesses up to 1-1/4 inches at 80,000 psi minimum yield strength; yield strength of 100 KSI with equal weldability is a goal.

In this project the 80 KSI steels up to 6 inches thick were tested in Phases I and II. Some plates were welded prior to age hardening. In phases III and IV, 100 KSI yield strength steels were aged prior to welding.

Welding processes used were those most generally applicable to shipbuilding, including shielded metal arc (SMAW), submerged arc (SAW), including narrow gap (NG SNAW), and gas metal arc, including pulsed arc (GMAW and PGMAW).

In some test assemblies the weld processes were intentionally pushed to relatively high heat input parameters to investigate the tolerance of ASTM A710 and modified ASTM A710 to high production rate welding. Little or no preheat and interpass temperature controls were used to see if these costs could also be avoided in production.

Electroslag welding (ESW), although not widely used in U.S. shipbuilding, is an extremely high production rate process but also results in extremely high heat input and it adversely affects adjacent base metal properties of higher strength steels. One test assembly was electroslag welded to evaluate the effect.

The times and temperatures used for precipitation hardening the various thicknesses and the resulting base plate physical properties are tabulated in

the report. This information will provide useful basic data for future reference in research with these materials.

The welding and testing of Phases I and 11 demonstrated that, even with tandem sub arc, heat inputs totaling over 150 kilojoules per inch, no base betal or HAZ cracking resulted. The practical limits of heat input were exceeded (intentionally) as evidenced by centerline cracking when heat input exceeded 250 kilojoules per inch. Typical HAZ charpy V-notch values for various processes and heat input levels were well above 50 lbs at 40 degrees F and consistently greater than 70 percent of base plate values for plates aged prior to welding.

The all-weld metal and charpy V-notch (CVN) test results are included in copies of test reports in the appendices for all test assemblies. All weld metal tensiles exceeded 80 ksi yield strength and consistently retained toughness (CVN) values greater than the 20 ft-lb at 40 degrees F for 80 ksi yield steel, specified by the American Bureau of Shipping for mobile offshore drilling units.

A comprehension overview and important test data for Phases I and II is presented in Appendices C and D which constitute part of this project report. Some data on the higher yield strength modified steel used in Phases III and IV is included in Appendix D which is an interim report on the project.

The steel under evaluation in Phases III and IV was modified to 100 ksi yield strength in thicknesses from 3/4 inch to 5 inch. Manganese was added up to 1.7 percent; molybdenum was upped to 0.5 percent; aluminum to 0.65 percent and a trace of boron was allowed. Chromium was reduced to 0.10 percent.

The welding consumables were selected by reference to vendor data sheets for high strength steels. Welding processes were Shielded Metal Arc, Gas Metal Arc, single and tandem sub arc, and electroslag. The electroslag welding was done on 3/4 inch thick plate for a case of extreme high heat input.

Tolerance of the steel to a wide range of weld heat input values was exhibited. There was no visible evidence of production of brittle phases and no cracking in base metal or HAZ. In general, there was good retention of HAZ toughness. However, the electroslag process did cause severe loss of both weld metal and heat affected zone toughness - not a surprising result since the heat input was over 5,000 Kilojoules/inch.

The Charpy V-notch tests were made at -60 degrees F in Phases III and IV. HAZ values (except as above) were between 53 and 197 ft-lbs for welding heat input ranging from 38 to 230 Kilojoules/inch. All weld-metal CVN’s were disappointingly low in the 100 ksi welds. Late in the project the cause was found to be largely due to a less than optimum selection of filler metal and flux and not attributable to either weld process or base metal.

Other combinations of wire and flux than those used in the subarc welds are available and should be investigated by persona interested in high heat input welding of HSLA steel with maximum retention of weld metal toughness.

Appendix A is lengthy but presents important details of weld joints, weld process parameters, electrodes, and weld sequences used for each material thickness and test results. Tranaverse and all weld metal teats results are given as well as impact test reports for plates and welds. Results are listed

for base metal, fusion line, and in the HAZ at Imm and 5mm. Evaluation of the broken samples is given in terms of percentage brittle versus cleavage mode failure.

The thickest test assemblies in Phase IV were sectioned, polished, and etched for metallographic examination of macro and microstructure. Macro photos of nital etch of the welds are reproduced in Appendix A which show the solidity of the welds and the successive weld bead overlay patterns and the extent of the heat affected zone into the base metal.

Microstructure photos show fine structure of the weld metal and base metal heat affected zones. Sheet A-57 is a characterization of the predominant metallurgical phases shown in the microstructure photos.

The successful production and welding of both 80 Ksi yield strength steel and modified ASTM A710 to over 100 Ksi yield strength in plate thicknesses greater than 5 inch thick is a major accomplishment of this project. Although some of the toughness properties in some weldments were not as high as expected the objective of demonstrating weldability with high heat weld processes was also accomplished. The details of weld process parameters and test results will provide a guide for further work in high production rate welding of the ASTM A710 and related HSLA steels.

Further development of weld metals and fluxes with toughness values more closely matching the base metal is needed for most productive use of these high yield strength steels in welded structures.

In preparation of the original report for publication several changes were made for clarification and format. No changes were made to the written text, however, several editorial insertions were added to direct the reader to the appropriate appendix sheets for technical details not covered by the text. The appendices were rearranged in an effort to lend continuity to the report. For example, the micro and microstructure photos were placed in sequence with test assembly, weld parameter, and physical test data sheets for Phase III and IV. Subject headings were added to the text and titles added to the appendix sheets from which a Table of Contents was developed. In Appendix B, a list of welding equipment was made to replace the vendor technical data sheets of the original report.

Foreword by O .J. Davis, SP-7 Program Manager.

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LIST OF COMMONLY USED ABBREVIATIONS

CVN	Charpy V-Notch
ESW	Electroslag Welding
GMAW	Gas Metal Arc Welding (MIG)
HSLA	High Strength Low Alloy Steel
KJ	Kilojoules
KJI	Kilojoules Per Inch (or KJ/in)
KSI	Thousand Pounds Per Square Inch
NGSAW	Narrow Gap Subarc Welding
PH Steel	Precipitation Hardened Steel
SMAW	Shielded Metal Arc Welding (Stick)

PREFACE

This report presents the results of a project initiated by SP-7, Welding Panel of the Ship Production Committee of the Society of naval Architects and Marine Engineers. Funding was provided by the U.S. Maritime Administration through a cost sharing contract between Newport News Shipbuilding and Dry Dock Corp. and Ingalls Shipbuilding, Inc. as contract management. Bethlehem Steel Corp., Beaumont Shipyard, also party to the contract was charged with accomplishing its goal, "Evaluate The Benefits of New Higher Strength Low Al1oy (HSLA) Steels."

The project was performed during the tenures of SP Panel Chairman B. C. Howser of NNS&D and L. G. Kvidhal of Ingalls. M. I. Tanner of NNS&D and O. J. Davis of Ingalls served as program managers of this project.

The project was executed under the leadership of A. T. Sheppard, Engineering Superintendent, and J. P. Stafford, Chief Engineer, Production, of Bethlehem's Baltimore Marine Division. Site work at the Beaumont Shipyard was carried out by members of the Welding Engineering Section of that division.

EXECUTIVE SUMMARY

The demand for offshore drilling rigs that are able to operate in deeper waters along with the expansion of U.S. Naval units accented the need for better higher strength steel to be used in building the same.

The steels available for us in the 80 to 100 ksi yield point range were not costly to procure, but fabrication and erection costs continued to escalate. This is primarily due to the high cost of sustained preheat and interpass temperature controls and the prohibited use of high heat inputs while welding. The U.S. Maritime Administration decided to find a solution to both the high cost of welding and subsequent improvement in productivity plus shorter delivery times. Thus, the project Evaluate the Benefits of New Higher Strength, Low Allow (HSLA) Steels" came into fruition.

ASTM A710 Grade A Class 3 steel, which is precipitation hardened, through 3" thick was used for material to meet or exceed an 80 ksi yield point requirement. The same material was used to meet or exceed a 70 ksi yield point through 6". The material was excellent, it can be welded without sustained preheat and there is no apparent limit on heat input.

However, physical limits to heat input were found. Above 250 KJ/in. sidewall erosion was pronounced and increasingly difficult to repair, thus sacrificing some of the potential savings the material provides to the shipbuilder. The larger mass of molten metal can overrun the sub-arc flux and trap slag under the deposit. This fact remains unknown until work is completed and inspected by NDT methods. Thus, costly excavation and weld repairs nullify any

potential savings. A similar physical problem occurs when using single arc SAW for narrow gap joints using a split layer technique. Some sidewall erosion repairs are almost impossible to make and costs increase exponentially. Due to these physical handicaps, out heat inputs were limited to 200 KJ/in. (total) for tandem SAW and 100 KJ/in. for the SAW narrow gap joint. However, these physical limitations do not impair the ability of the base metal to withstand high heat input.

For Phases III and IV, a modified chemistry 100 ksi yield point precipitation hardened steel was specified which had been experimentally produced by an inactive domestic producer. A foreign producer was soon located who agreed to supply the limited amount of material made to this formulation that was needed to perform this task. This material too can be welded without sustained preheat and interpass controls. The same physical. limits on heat input that were discovered in Phases I and II had to be followed. The material has the potential to deliver considerable savings in production costs at the 100 ksi yield point level. However, the physical limitations will deter the full realization of this potential until they are overcome.

In Phase IV, different SAW consumables were used since the previously used ones were not longer available. A severe loss of weld metal toughness was discovered although the base material was relatively unaffected. This fact underlines the need for improved welding consumables.

CONCLUSIONS

1. Precipitation hardened base material is available up to a 100 ksi yield point that can be welded without sustained preheat or heat input limitations. Sizeable savings can be realized by their use. These materials offer savings to other steel industries, such as pressure vessels, bridges and building construction. They can replace such steels as ASTM A514, 517, 542, 543, 709 Grade 100 and many others. Thus the entire steel fabrication industry as well as shipbuilding would benefit from their use.

2. A concerted effort by the shipbuilding industry to use these materials would result in savings in many areas. Lighter plate decreases the structure’s deadweight which increases its payload or decreases the power to propel it. Lighter plate increases the length and width of plates possible to be ordered from the mill. This in turn reduces the number of welds to be made. Lighter and larger plates will reduce handling times at the working area. Less money wil be paid out in freight.

3. The physical limitations experienced need resolution. This would require more time for research and additional funding.

4. The mechanical properties of ASTM A710 should be upgraded for material 2 inches and down. The 20 percent additional increase in yield from 65 to 80 ksi would enable designers to use thinner plate to accomplish their task. Thus, savings would be further enhanced by its use.

5. Better welding consumables are sorely needed. Consumable producers, like steel producers, are hesitant to pioneer new markets with low volume requirements. The accomplishments of the above conclusions will hasten this improvement. The shipubilding industry is urged to actively pursue these points.

BVALUATE THE. BENEFITS OF NEW HIGHER STRENGTH

LOW ALLOY (HSLA) STEELS

1.0 INTRODUCTION

1.1 Background. Bethlehem proposed to SP-7 to conduct a study to evaluate the benefits of new higher strength low alloy (HSLA) steels. The original goals of the November, 1983 proposal appear in Figure 1. In February, 1985, $95,000 was awarded to accomplish Phase I, and work on Phase I began in August, 1984. During the course of Phase I, $75,000 was awarded for Phase II.

In Phases I and II, we would determine the ability of the new HSLA steels to withstand high welding heat inputs, without using sustained preheat, and have only limited heat zone degradation. Yield points to be attained were 80 ksi through 3 inches thick; 75 ksi through 5 inches thick; and 70 ksi through 6 inches thick.

The HSLA to be used was ASTM A710, Grade A, Class 3. Its properties appear in Figure 2.

In late 1984, a search was begun for a producer of the 100 ksi yield point plates needed in Phases III and IV-A. U.S. producers were unwilling to commit to produce this new chemistry plates in any amount less than 100 tons. A foreign producer was located who was iwlling to accept an order for 20 - 25 tons that could be made in their small 60-ton unit. Properties of these plates are compared to ASTM A710 Grade A, Class 3, and shown in Figure 10.

In June, 1985, an order was placed for 22 tons of the new chemistry steel at a cost of .58/lb. Total cost including freight was $27,460.50 and it was delivered in early 1986.

PANEL Sp-7 ORIGINAL GOALS

PHASE	GOAL AND PLATE THICKNESS	SCHEDULED COST	TIME
1	80 KSI YP THROUGH 3 IN.	$ 95,000	1 YEAR
2	75 KSI YP THROUGH 5 IN. 70 KSI YP THROUGH 6 IN.	$ 75,000	9 MONTHS
3	100 KSI YP THROUGH 3 IN.	$ 70,000	6 MONTHS
4A	90 KSI YP THROUGH 5 IN. 85 KSI YP THROUGH 6 IN.	$ 100,000	1 YEAR
4B	PUBLISH RESULTS	$ 50,000	9 MONTHS
TOTALS		$390,000	4 YEARS

PANEL Sp-7 REVISED GOALS

PHASE	GOAL AND PLATE THICKNESS	SCHEDULED COST	TIME
1	80 KSI YP THROUGH 3 IN.	$ 95,000	1 YEAR
2	75 KSI YP THROUGH 5 IN. 70 KSI YP THROUGH 6 IN.	$ 75,000	9 MONTHS
3	100 KSI YP THROUGH 3 IN.	$ 51,000	6 MONTHS
4A	90 KSI YP THROUGH 5 IN. 85 KSI YP THROUGH 6 IN.	$ 70,900	9 MONTHS
4B	PUBLISH RESULTS		
TOTALS		$291,900	36 MONTHS

Figure 1. Plate Thickness and Yield Strength Goal

PHASES I & II

ASTM A710 GRADE A CLASS 3

ELEMENT	COMPOSITION %
C	0.07
Mn	0.40–0.70
P	0.025 MAX
S	0.025 MAX
Si	0.40 MAX
Ni	0.70–1.00
Cr	0.60–0.90
Mo	0.15–0.25
Cu	1.00–1.30
Cb	0.02 MIN

MECHANICAL PROPERTIES FOR MATERIAL UNDER 2 INCHES

TS min	75 ksi
YP min	65 ksi
% E min	20

SUPPLEMENTAL REQUIREMENT
TRANSVERSE "V" 50 FT-LBS AT −80°F

Figure 2. Chemical and Mechanical Properties of ASTM A-710, Grade A, Class 3

Work was completed on Phase II, somewhat short of the original goal of 48 test assemblies for Phases I and II. Of the 30 plates prepared, twenty-four (24) were acceptable and six (6) were scrapped. Results of the findings are discussed later.

In May, 1986, Bethlehem was advised that MARAD funds were not longer available to do Phases 111, IV-A, and IV-B. A proposal was then submitted to produce a shortened version of Phase 111 for $51,000 and a stringently curtailed version of Phase IV for $70,000. These revised goals also appear in Figure 1.

Work on Phase III began in November, 1986 and was completed in March, 1987. Work on Phase IV began March 18, 1988 and was completed in November, 1988.

1.2 Requirements and Welding Practices. In all phases, the following requirements and practices were followed to simulate actual produciton methods:

a. Initially, heat input was unlimited but physical limitation were found.

b. Only gas torch moisture-drying preheat was to be used, when needed.

c. Sustained preheat and interpass temperature controls were abandoned.

d. Degradation by cracking of the weld or heat zone was prohibited.

e. The average sum of heat affected zone charpys to be no less than 60 percent of the parent plate.

2.0 PHASE I - WELDING ASTM A710 , GRADE A STEEL PLATE FROM 2-314-INCH TO 3-INCH THICK

2.1 Objectives of Phase I. The goal was to produce 80 ksi yield point welded joints in steel through 3 inch thick. Transverse inpact values as required by American Bureau of Shipping 1985 "Rules for Building and Classing Mobile Off shore Drilling Units," Table B. 2 Grade EQ56 (56 k/mm^2 or 80 ksi minimum yield), High Strength Q&T steel, of 20 ft.-lb. at -40 degrees F were to be met or exceeded, and a minimum elongation of 16 percent was to be met.

2.2 Approach. The steel welded in Phase I was ASTM A71O, Grade A, Class 3. (See Figure 2) The plates were procured in the quenched only condition. Eight (8) test plates were welded in this condition and then precipitation hardened (P/H). Seven (7) test plates were P/H first and then welded. The graph shown in Figure 3 depicts the various properties that can be obtained at different P/H temperatures and rapid cooling to ambient conditions. Therefore, ASTM's minimum of 65 ksi yield point over 2 inch can be exceeded with certainty.

2.3 Advantages of Welding Prior to Age Hardening. Using plate in the quenched only condition, presents the fabricator with an extraordinary production improvement. This occurs because of the increase in yield strength that is brought about by the precipitation-hardening process. For example, a 3-inch thick A710 Grade A, Class 3 plate will have an approximate yield point of. 60 - 64 ksi in the quenched only condition, and average 86 ksi when precipitation-hardened at 1050 degrees F. Therefore, 3 inch plate with an 80 ksi yield point is an actuality. Thus, a minimum of 25 percent increase in forming ability can he

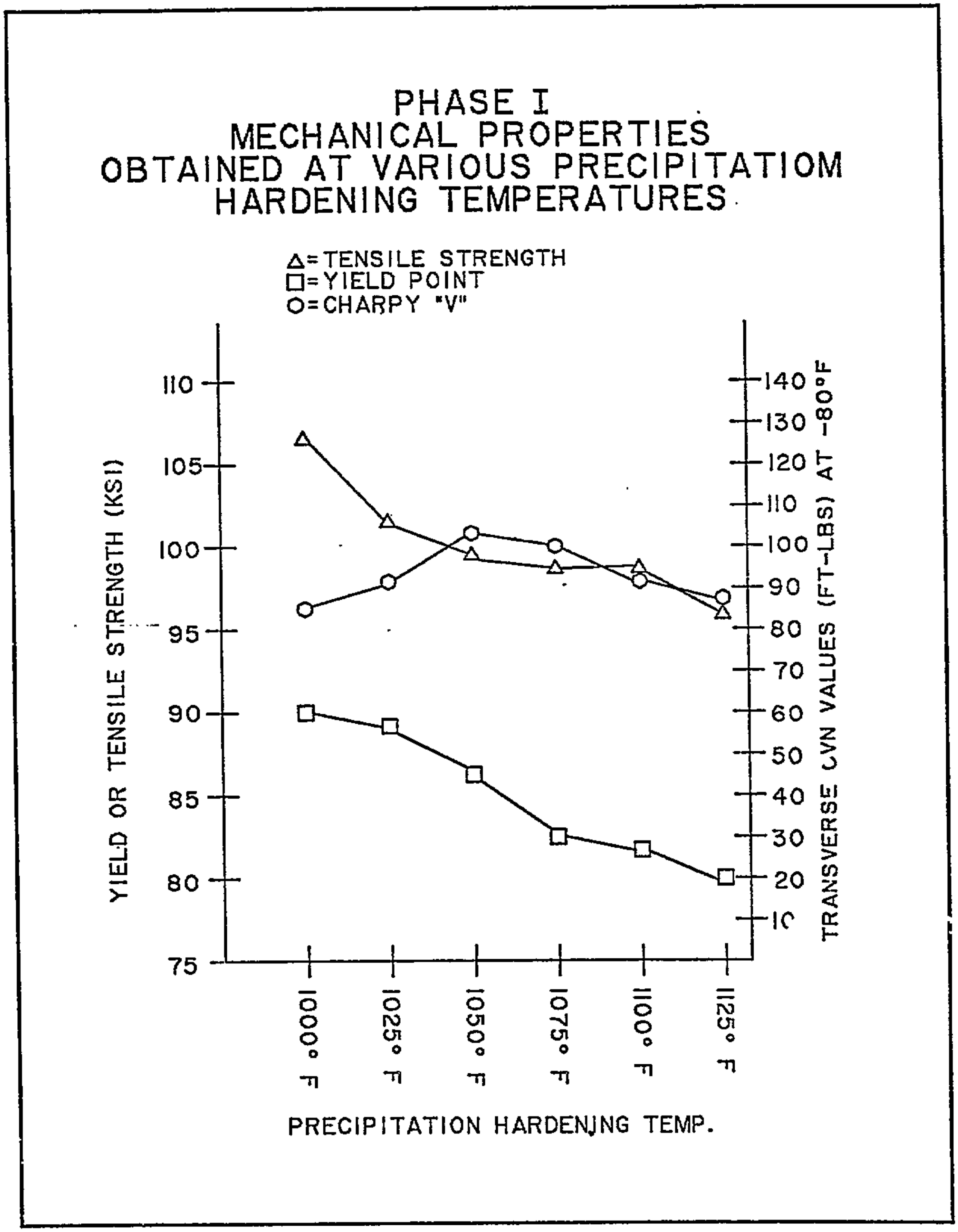


Figure 3. Tensile, Yield and Charpy versus Precipitation Hardening Temperature for Test Plate

achieved--8O/62 = 1.29. Assume that a plant's forming equipment capacity for a 3 inch 80 ksi yield point plate is 72 inches wide at a given radius. By using a 62 ksy yield point material, the forming width capacity will be increased to 90 inches. Then a 90/72 = 1.25 ratio exists. Wider plate can be formed and the number of weld butts can be reduced by 25 percent for a given assembly. The assembly can then be precipitant ion-hardened and welded.

2.4 Mechanical Properties of Test Plates. The graph of mechanical properties are the results of using quenched only plates from the producer and precipitation-hardened on site. The graph also shows charpy V-notch values at -80 degrees F. ASTM A71O supplemental requirement No. S1.3 states that test results for longitudinal specimens (transverse notch) "shall meet a minimum value of 50 ft.-lb. at - 80 degrees F." Charpy values in the quenched only condition were not considered germane. (See Figure 3.)

Test plates were cut, beveled and fitted, as shown on Figure 4, three sheets.

2.5 PHASE I RESULTS

2.5.1 Welding Prior To and After Precipitation Aging - 2-1/4 Inch to 3 Inch Thick Plates. The first three (3) of the four (4) groups of welded test plates were welded prior to precipitation hardening. The fourth group was precipitation-hardened and then welded. The fourth group was precipitantion-hardened and then welded. Charpy values in the quenched only condition were not germane. The material in the second group (2-1 /4 inches) was furnished by Lukens Steel, the remainder was furnished by Armco, Houston. Phase I results appear in Figure 5.

WELD JOINT DESIGN

PHASE I (SHEET 1)

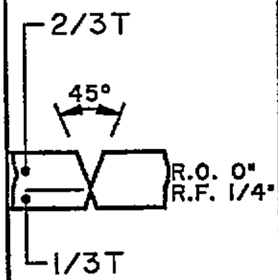
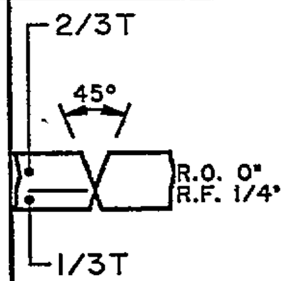
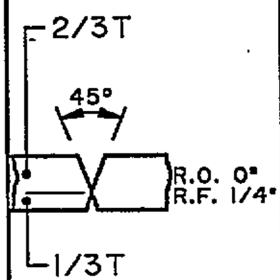
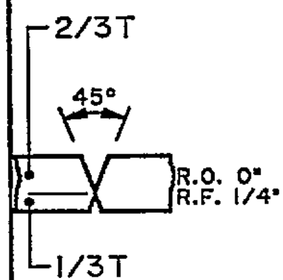
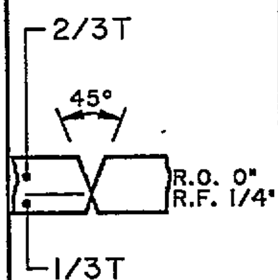
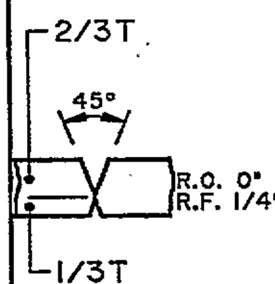
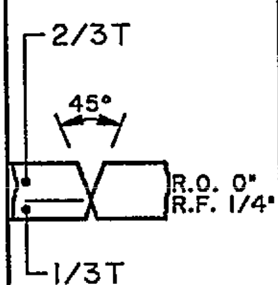
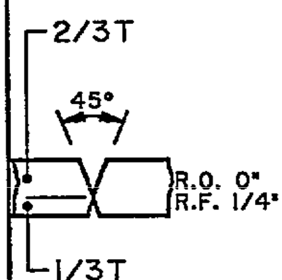
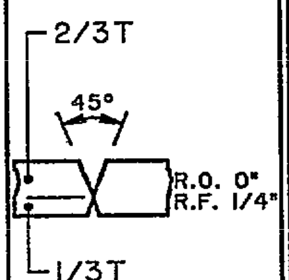
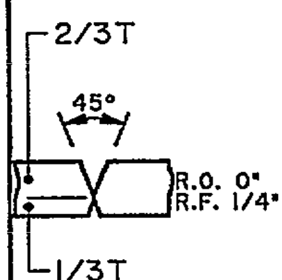
PL#	THK.	PROCESS	JOINT DESIGN	PL#	THK.	PROCESS	JOINT DESIGN
A	2 3/4"	SAW		F	2 3/4"	SAW	
B	2 3/4"	SAW		G	2 3/4"	SAW	
C	2 3/4"	SAW		H	2 3/4"	SAW	
D	2 3/4"	SAW		I	2 3/4"	SAW	
E	2 3/4"	SAW		J	2 3/4"	SAW	

Figure 4. Weld Joint Designs for 2-1/4-Inch to 3-Inch Thick Plates for Various Arc Weld Processes (Sheet 1 of 3)

WELD JOINT DESIGN

PHASE I (SHEET 2)

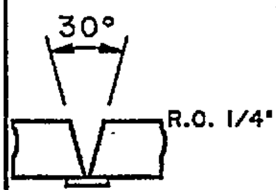
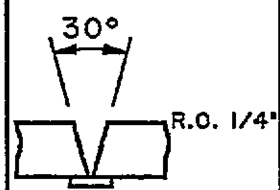
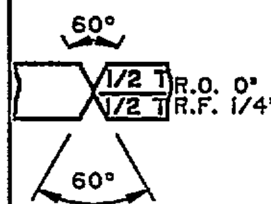
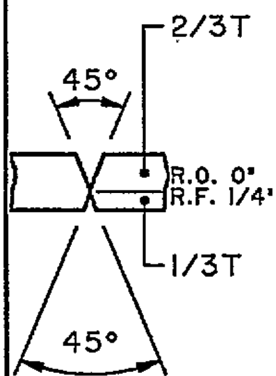
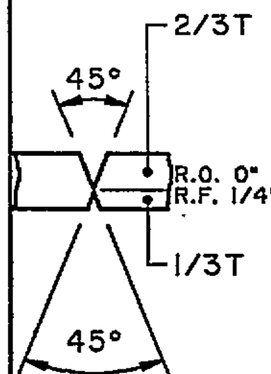
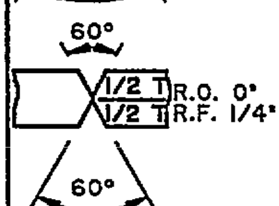
PL#	THK.	PROCESS	JOINT DESIGN	PL#	THK.	PROCESS	JOINT DESIGN
K	2 3/4"	SAW		O	2 3/4"	NARROW GAP SAW	
L	3"	SAW		Q	2 3/4"	SAW	
M	2 3/4"	SAW		T	2 1/4"	SAW	
N	3"	NARROW GAP SAW		U	2 1/4"	SAW	

Figure 4. Weld Joint Designs for 2-1/4-Inch to 3-Inch Thick Plates for Various Arc Weld Processes (Sheet 2 of 3)

WELD JOINT DESIGN

PHASE I (SHEET 3)

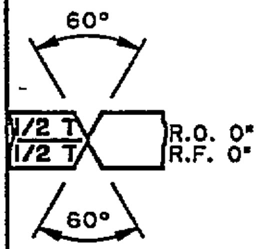
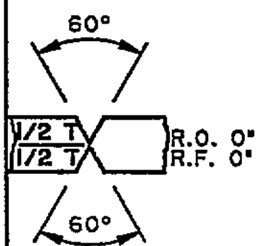
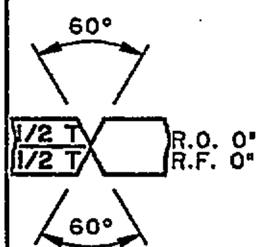
PL#	THK.	PROCESS	JOINT DESIGN	PL#	THK.	PROCESS	JOINT DESIGN
V	2 1/4"	GMAW					
W	2 1/4"	SMAW					
X	2 1/4"	SMAW					

Figure 4. Weld Joint Designs for 2-1/4-Inch to 3-Inch Thick Plates for Various Arc Weld Processes (Sheet 3 of 3)

PHASE I RESULTS

THICK-NESS	PROCESS	KJ/IN INPUT	Y.P. (KSI)	T.S. (KSI)	% E	% RA	*CHARPYS AT -80°F W	F	1 MM	3 MM	5 MM
(PRECIPITATION HARDENED AT 1050°F FOR 165 MIN AFTER WELDING)											
2 3/4	DC & AC SAW	208	87.2	107	22	63	9	8	30	41	22
2 3/4	*	175	89.2	108	22	58	11	10	64	27	20
(P/H AT 1100°F FOR 165 MIN AFTER WELDING, CHARPYS AT -40°F)											
2 1/4	DC & AC	135	93.2	108	26	69	23	98	63	103	103
2 1/4	VERT-STICK	65	89.6	100	26	72	15	173	136	151	117
(P/H AT 1050°F FOR 165 MIN AFTER WELDING, CHARPYS AT -40°F)											
2 3/4	DC & AC SAW	150	91.1	107	26	67	31	51	53	48	43
2 3/4	*	125	87.9	107	24	66	28	46	52	48	43
2 3/4	*	100	93.2	107	26	67	43	58	77	38	32
2 3/4	DC ONLY	75	94.3	106	26	68	29	15	46	33	29
(P/H AT 1050°F FOR 165 MIN BEFORE WELDING, CHARPYS AT -40°F)											
2 3/4	DC & AC SAW	100	97.6	109	24	67	76	54	50	80	103
2 3/4	*	150	88	108	24	69	78	109	74	64	102
3	*	200	84.7	106	23	67	40	94	88	95	56
3	DC ONLY	75	94.7	106	24	67	74	86	52	72	91
3	DC & AC	125	89.7	107	24	63	86	96	76	64	94
3	DC N.G.	75	93.4	106	25	66	61	68	112	73	67
2 3/4	VERT. MIG.	95	88.7	102	23	58	79	110	109	93	69

*ALL CHARPY "V"S ARE TRANSVERSE

Figure 5. Weld Process, Heat Input Values and Test Results of 2-1/4-Inch to 3-Inch Thick Weldments

2.5.2 Dual Sub-Arc Welds of 2-3/4-Inch Plate to 208 KJ/IN Heat Input. In the first group of 2 inches to 2-3/4 inches plates mechanical properties at high heat input were satisfactory. Weld metal charpy values were not. The average of the 1, 3, and 5mm HAZ was less than 60 percent of the 100 ft .-lb. expected (Figure 3) . The pitfalls that can be encountered by precipitation hardening after welding were evident.

2.5.3 Dual Sub-Arc and SMAW Welding 2-1/4-Inch Plate to 135 KJ/IN Heat Input. In. the second group, where more heat waa used for soaking and toughness level was lowered to -40 degrees F, a marked improvement in HAZ values occurred and there was some improvement of weld metal charpys. The vertical-stick plate was repaired and rewelded twice in some places after defects were discovered by ultrasonic inspection. It is believed that rewelding and the reheating, including precipitation hardening of the weld metal was responsible for the low, 15 ft.-lb. charpy value. (See Figure 6.)

2.5.4 Dual Sub-Arc and Single Sub-Arc Welding at 75 to 150 KJ/IN Heat Input. In the third group, which has a lower soak temperature, all weld metal charpys are acceptable. HAZ charpy values are below the 60 percent average of base plate value. The heat inputs and values obtained in the third group duplicates production procedures that have been used. The low fusion line value on the single arc narrow gap weld, of 15 ft .-lb. is attributed to rewelding and reheating to repair weld defects. (See Figure 5.)

2.5.5 Single and Dual Sub-Arc, and Vertical Mig Welding after Precipitation Aging. All material in Group 4 was precipitation hardened prior to welding. Weld metal charpys` are excellent. Heat affected zone values, including fusion line readings are at least 72 percent or better of initial properties. (See Figure 6.)

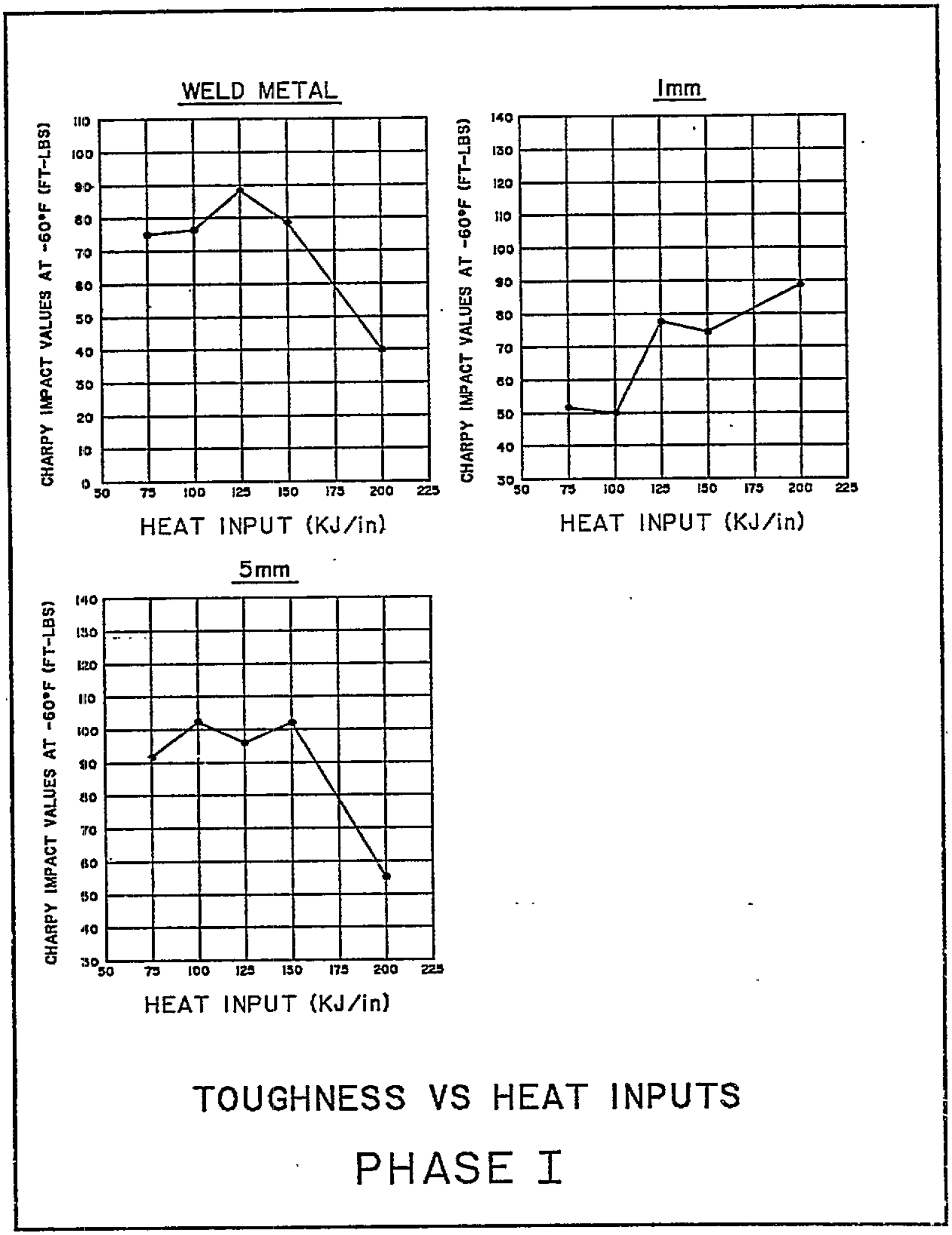


Figure 6. Graph of Weld Metal and Heat Affected Zones (Charpy V-Notch Results of 2-1/4-Inch to 3-Inch Thick Weldments)

3.0 PEASE II - WELDING 80 KSI YIELD STRENGTH PLATES FROM 4-INCH TO 6-INCH THICK

3.1 Base Plate Properties. Material for Phase 11 was procured from steel service centers. The 4-1/2 inch and 5 inch plates were produced by Armco and sold to a service center upon the closing of their Houston works. They had an average longitudinal charpy value of 175 ft .-lb. at -50 degrees C. The 4 inch and 6 inch were produced overseas with a longitudinal charpy value of 155 ft. -lb. at -50 degrees C. All were in the precipitation hardened condition in accordance with ASTM A71O, Grade A, Class 3. Based on the above, parent metal transverse charpy values attainable should be 116 ft .-lb. for 4-1/2 inch and 5 inch material and 103 ft .-lb. for 4 inch and 6 inch plates at -50 degrees C prior to welding. This transverse to longitudinal ration complies with ABS 1985 Mobile Offshore Drilling Unit Rules.

3.2 Yield Strength Goals of Phase 11. The goal of Phase 11 differed from Phase I in that material through 5 inches would have a 75 kai yield point and 6 inch material would have only a 70 ksi yield point. The 60 percent retention of WAZ properties was to be maintained.

3.3 Joint Displays for Various Weld Processes and Thicknesses. The weld joint designs used in Phase 11 appear in Figure 7, 2 sheets.

3.4 PEASE 11 RSSULTS

a. The goals of 75 ksi and 70 ksi yield points through 5 inches and 6 inches were attained. (See Figure 8.)

b. The 60 percent of original transverse charpy value was realized in the heat affected zone averages.

WELD JOINT DESIGN

PHASE II (SHEET 1)

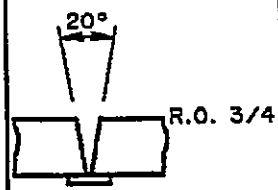
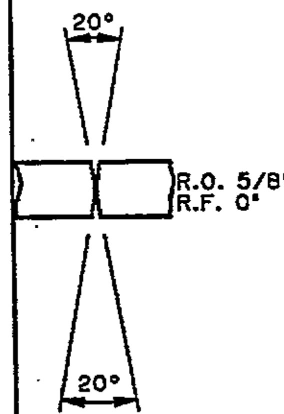
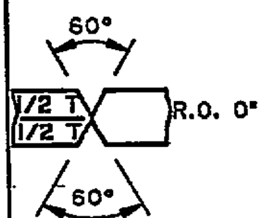
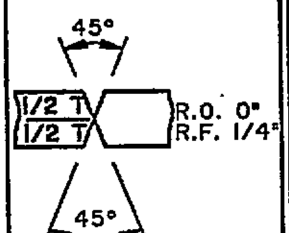
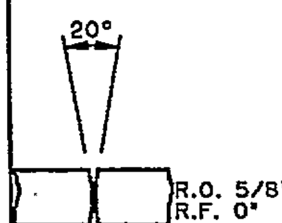
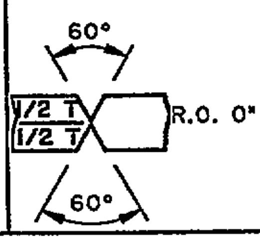
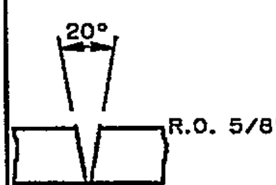
PL#	THK.	PROCESS	JOINT DESIGN	PL#	THK.	PROCESS	JOINT DESIGN
AA	4"	SAW		GG	5"	SAW	
BB	4"	SMAW/ GMAW		HH	5"	NARROW GAP SAW	
CC	4 1/2"	NARROW GAP SAW		II	6"	NARROW GAP SAW	
DD	4 1/2"	SMAW/ GMAW		JJ	5"	SAW	
EE	4 1/2"	SMAW/ GMAW		KK	6"	SAW	

Figure 7. Weld Joint Design Used in 4-inch to 6-inch Thick Weldments (Sheet 1 of 2)

WELD JOINT DESIGN

PHASE II (SHEET 2)

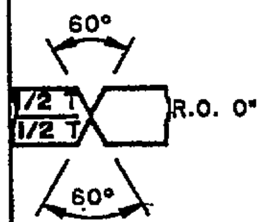
PL#	THK.	PROCESS	JOINT DESIGN	PL#	THK.	PROCESS	JOINT DESIGN
LL	6"	FCAW					

Figure 7. Weld Joint Design Used in 4-inch to 6-inch Thick Weldments (Sheet 2 of 2)

PHASE II RESULTS

(PRECIPITATION HARDENED AT 1100°F FOR 135 MINS. PRIOR TO WELDING)

THICK NESS	PROCESS	KJ/IN INPUT	Y.P. KSI	T.S. KSI	*CHARPYS AT -40°F W	I M/M	5 M/M
4	DC & AC SAW	192	84	99	30	86	94
4	VERT. MIG.	55	87	100	84	83	82
4 1/2	SAW - NG	73	78.1	90	71	139	134
4 1/2	VERT - STICK	55	79.6	90	33	112	117
4 1/2	VERT. MIG.	73	76.5	88	59	160	129
5	DC & AC SAW	140	78.4	86	37	132	131
5	SAW - NG	75	79.4	90	87	135	172
6	DC & AC SAW	130	80.9	95	64	77	59
6	SAW - NG	75	84.6	92.7	51	71	89

***ALL CHARPY "V"S ARE TRANSVERSE**

Figure 8. Mechanical Properties of 4-inch to 6-inch Thick Weldments

4.0 PHASES I AND II COMMENTS

a. Goals of 80 ksi yield point through 3 inch, 75 ksi, and 70 ksi yield points through 5 inches and 6 inches have been met.

b. Only moisture drying preheat was used.

c. No cracking occurred in the parent metal or its heat affected zone. High heat inputs were used. Up to 200 + KJ/in. , the sum of two (2) arcs was maximum. (Weld metal and HAZ charpy V-notch values at lmm and 5mm are tabulated in Figure 8.)

d. Heat affected zone values were at least 70 percent of original when plates were precipitation hardened before welding. The same would be true for formed or rolled subassemblies. These findings parallel those reported by G. E. Kampschafer.

e. Some fabrication can be welded prior to precipitation hardening at some additional sacrifice of properties. Results obtained must still meet ABS or other governing specifications.

f. Welding consumables used were:

SMAW - E-I1018M - Alloy Rods

GNAW - Linde 95 - Argon with 25 percent CO*

SAW - Armco W-24 with Lincoln 880M Flux

SAWNG - Linde 100 with Linde 0091 Flux

g. The results as posted are optimums. Several plates were welded at higher heat inputs than shown and were unacceptable for the following reasons:

1. Weld centerline cracking became apparent on three (3) sub-arc plates when gouging to prepared for the second side weld. (1 - 3 inch; 1 - 4 inch; 1 - 6 inch; total heat inputs of 185 + 150 = 335 KJ; 150 + 125 = 275 KJ, and ,125 + 125 = 250 KJ/in.)

2. With high heat at the slower travel speeds weld nugget size is magnified. Trapped fused slag in the weld metal is not known until plate is X-rayed or ultrasonic readings are made. (Two (2) plates scrapped, 1 - 2-3/4 inch, 280 KJ total input; 1 - 4-1/2 inch, 150 lead, 125 trail, 275 total input).

3. Narrow gap by SAW had to be limited to single arc at less than 100 KN/in. input. Sidewall undercut becomes a major problem and resultant trapped slag is very costly to remove.

h. Charpy V-notch values vs. heat input are plotted for Phase I in Figure 13. Phase 11 comparisons appear in Figure 9.

i. Appendix C contains a paper entitled, “The Benefits of New High Strength Low-Alloy (HSLA) Steels ,“ covering Phases I and 11 in great detail and was delivered at the 1987 AWS Convention in Chicago. Appendix D contains a paper entitled, “The Benefits of A Mo”dified Chemistry, High Strength Steel, ” which has a discussion and author’s closure sect ion covering many vital points concerning 100 ksi yield point steel.

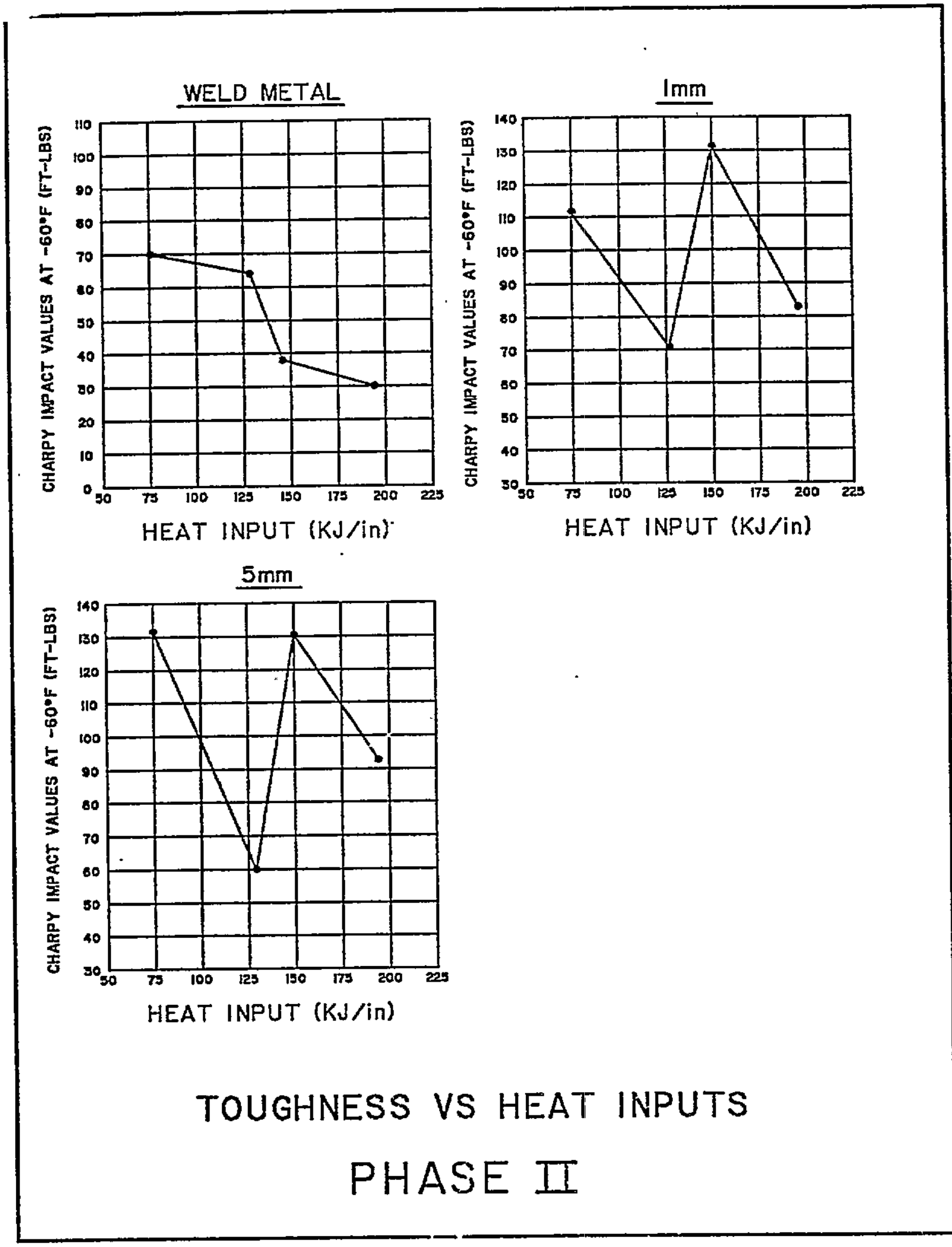


Figure 9. Graphs Weld Metal and Arc Heat Affected Zone Charpy V-Notch Values Versus Welding Heat Input for 2-1/4-Inch to 3-Inch Thick Weldments of 80 Ksi Yield Strength Steel

5.0 PEASE III - NELDING ASTM A710 GRADE A, CLASS 3 MODIFIED TO 100 KSI YIELD STRENGTH To 3-1/4 mm THICK

5.1 Objective of Phase III. The primary objective of Phase III was to qualify HSLA A710, Class 3 (modified) with 10II ksi minimum yield in thicknesses ranging from 3/4 inch through 3-1 /4 inch using various welding processes, and achieve weld metal mechanical and toughness properties that would meet or exceed MIL-STO-248C requirements.

5.2 Chemistry, Weld Processes, and Joint Designs. The properties of this modified steel are compared with ASTM A710 in Figure 10. Mn and Mo were markedly increased while Cr was halved and trace elements appear. Welding processes used for this task included SMAW, GMAW (low deposition) , SAW, TANDEM SAW, and ESW (high deposition) . Additionally, minimal preheating of test assemblies and higher (650 degrees F maximum) interpass temperature were examined to determine the ability of the material to yield satisfactory weld properties under less than optimal welding conditions. The weld joint designs used are presented in Figure 11. Eight test assemblies were prepared and welded. Welding parameters, techniques and laboratory reports are given in Appendix A. (Appendix A includes sketches of the joint designs and details, including the bevel angles root openings, and filler metals used for each thickness of weldment and weld process. The joint design sheets also provide details of weld pass sequence travel speeds, and electrical parameters used. The total weld heat input is alao given. Following the joint design sheet for each plate are the independent laboratory test reports with actual test results for each sample, including tensile strength, yield strength, and location of fracture. For charpy V-notch test data, the location of the sample with respect

PHASES III & IV

MODIFIED-CHEMISTRY PLATE COMPARISON

ELEMENT	COMPOSITION % A710 GRADE A CLASS 3	COMPOSITION % A710 GRADE A MODIFIED
C	0.07	0.07
Mn	0.40-0.70	1.20-1.70
P	0.025	0.025
S	0.025	0.025
Si	0.40	0.40
Ni	0.70-1.00	0.70-1.00
Cr	0.60-0.90	0.10-0.50
Mo	0.15-0.25	0.20-0.50
Cu	1.00-1.30	1.00-1.35
Cb	0.02	0.02
Al	N/A	0.015-0.65
B	N/A	T

MECHANICAL PROPERTIES FOR MATERIAL UNDER 3 INCHES

	COMPOSITION % A710 GRADE A CLASS 3	COMPOSITION % A710 GRADE A MODIFIED
TS min	75 ksi	125 ksi
YP min	65 ksi	100 ksi
% E min	20	20
% RA "Z"	N/A	25
"V" ft/lb °F "T"	50 at -80°	
"V" ft/lb ABS - FQ70 at-76°F MODU 1985 Table B.2		30L 20T

Figure 10. ASTM A710, Grade A, Class 3 Steel Modified to Reach 100 Ksi Yield Strength

WELD JOINT DESIGN

PHASE III

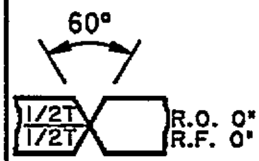
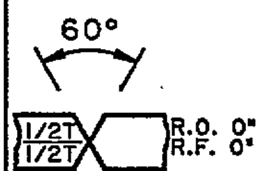
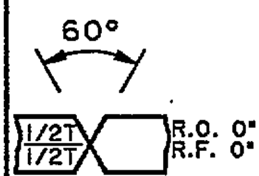
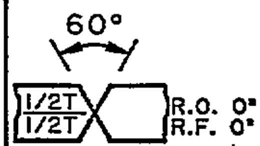
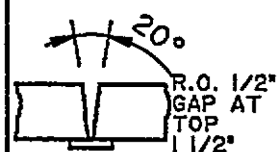
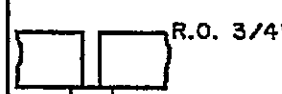
PL#	THK.	PROCESS	JOINT DESIGN
1	3/4"	GMAW	
2	1 1/4"	GMAW	
3	1 1/4"	SMAW	
4	1 3/4"	DUAL SUB ARC	
5	2 1/4"	SAW	
6	2 3/4"	DUAL SAW	
7	3 1/4"	ESW	
8	3 1/4"	SAW (NARROW GAP)	

Figure 11. Weld Joint Designs and Weld Processes Used to Weld 3/4-Inch Thick 100 Ksi Yield Strength, Modified ASTM A710, Grade A

to weld metal and heat affected zone and base metal, and the percentage of shear is given for each sample. A macro photo of test assembly plate III-8 is shown in figure on page A-27 for base metal plates, mill inspection certificates with additional data on physical poperties, chemistry, charpy V-notch values, heat treat schedules and hardness test results are presented on pages A-99 through A-104 - Addendum by O. J. D.)

5.3 Welding Consumables for Phase 111. Welding consumables used in this study and the various welding processes included:

SMAW	EI1OI8-M	Allow Rods "Atom Arc[r]' Electrodes
GMAW	ER120S-1	L-'Tec 120 Wire with 98 percent AR - 2 percent Oxy Shielding Gas
SAW	F11A4-SM5-G	Linde 100 Wire with Linde 009' Flux
	F1OA6-EF6	Armco W-25 Wire with Oerlikon 0P12 ITT Flux
Ews	F7A2-E144-M4	Linde 120 Wire with Linde 124 Flux

5.4 Mill Analysis and Test Reports of Base Metal Plates. Mill test reports for these modified chemistry plates appear in Appendix C. Mil test reports show that plates were water quenched and precipitation hardened at the following times and temperatures:

Immersion Quenching - All of one size at once - Chiba Works 12-26-85

Thickness (In)	WQ °F	Minutes	Ph °F	Minutes
3/4	1700	45	1220	130
1-1/4	1700	70	1166	150
1-3/4	1700	95	1166	175
2-1/4	1700	115	1166	200
2-3/4	1700	135	1166	230

3-1/4	1700	Very Rapid 1166	155
3-3/4	1700	Very Rapid 1166	260
4-114	1700	Very Rapid 1166	280
4-3/4	1700	Very Rapid 1175.	320
4-1/4	1700	Very Rapid 1166	340

5.5 PHASE III RESULTS (See Figure 12)

a. Transverse weld metal tens ion tests exceeded 100 ksi minimum yield on all test assemblies, except numbers 2 and 8. Plate 8 was electroslag welded at 5,770 KJ/in.

b. The A1l-Weld Metal Tension Tests exceeded 100 ksi minimum yield only on test plates with effective heat inputs of less than 50 R.J/in.

c. Charpy V-notch Weld Metal Impact Tests exhibited satisfactory results with heat inputs up to 130 R. J/in.

d. Charpy V-notch Base Metal HAZ Impact Tests were excellent, even with effective heat inputs of 230 RJ/in. Testing of all charpys was at -60 degrees F (-51 degrees C) .

e. Criticality of alignment between weld nozzle to joint groove is high using the sub-arc narrow gap process.

f. Wide range welding parameters produced no occurrence of base metal or heat-affected-zone (RAZ) cracking. This immunity to hydrogen induced cracking is primarily attributed to the low carbon content of the material, which hardens only slightly when quenched from austenite.

g. High heat input welding processes did not produce unfavorable dendritic grain growth in the weld metal or heat-affected-zone microstructure.

h. Charpy notch values vs. heat input are plotted in Figure 13.

PHASE III RESULTS

THICK-NESS	PROCESS AND CONSUMMABLES	KJ/IN INPUT	ALL WELD METAL Y.P.	T.S.	%E	REDUCED SECTION %RA	Y.P.	T.S.	*CHARPYS AT -60°F W	1 MM	5 MM
3/4	GMAW-98%A LINDE 120	38	111	125	17	49	105	115	69	96	82
1 1/4	GMAW-98%A LINDE 120	38	127	131	12	37	99	120	73	73	64
1 1/4	SMAW E11018M	27	112	124	+	+	110	116	24	65	61
1 3/4	DC-AC SAW LINDE 100W/ 0091 FLUX	230	87	120	23	51	103	112	16	53	73
2 1/4	DC-AC SAW LINDE 100W/ 0091 FLUX	127	97	113	23	64	103	111	31	54	50
2 3/4	DC-AC SAW ARMCO W/25W/ OP121TT FLUX	125	TEST NOT MADE				101	112	49	74	70
3 1/4	DC-NGAP ARMCO W/25W/ OP121TT FLUX	75	76	77	+	+	105	115	51	116	138
3 1/4	ESW LINDE 120 W/ 124 FLUX	5,770	67	106	16	34	90	135	7	3	5.5

*ALL CHARPY "V"S ARE TRANSVERSE

+BROKE OUTSIDE OF GAUGE MARKS

Figure 12. Physical Properties of 3/4-Inch to 3-1/4-Inch Thick Welds of 100 ksi Yield Strength Steel

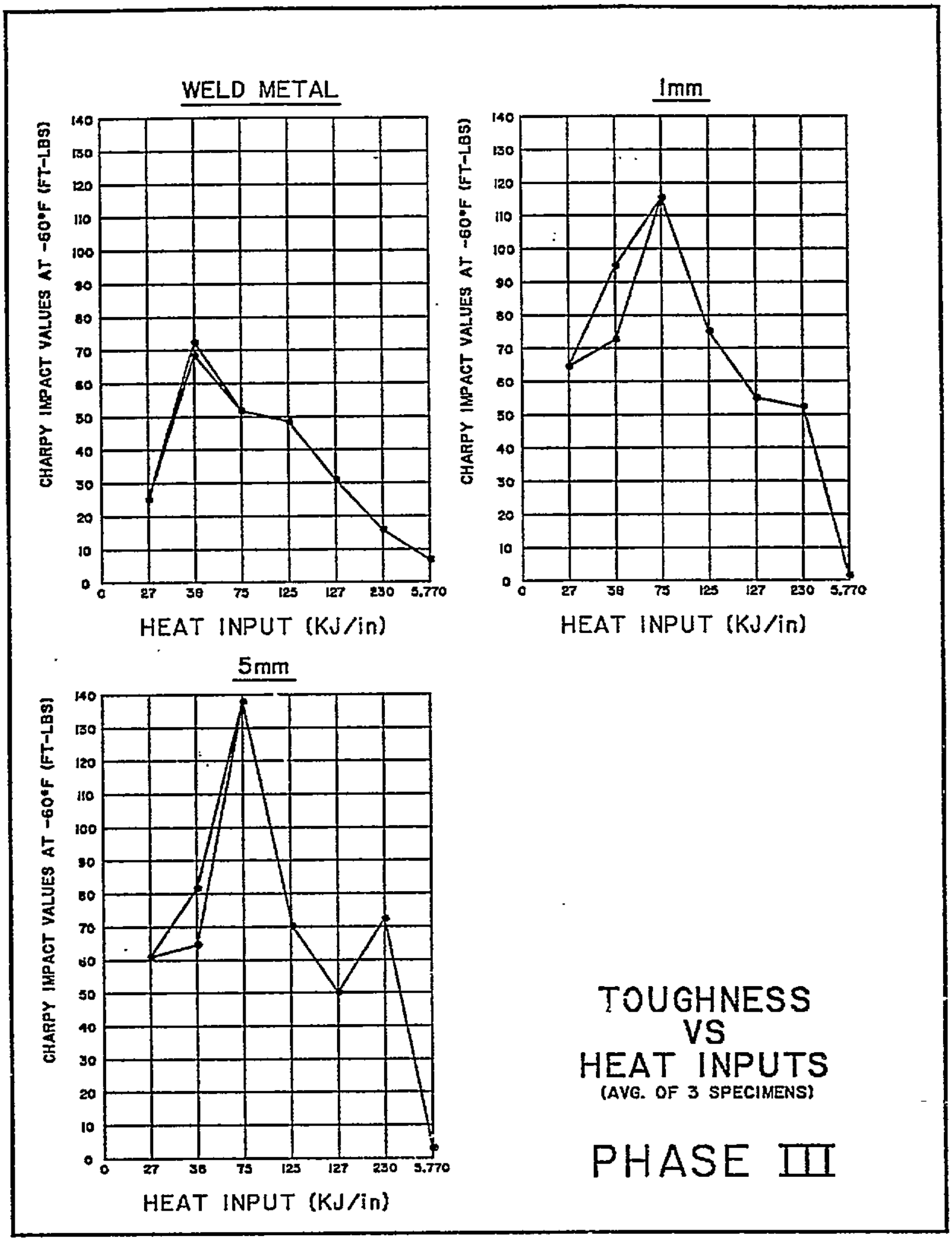


Figure 13. Graphs of Weld Metal and Heat Affected Zone Toughness for 3/4-Inch to 3-1/4-Inch Thick Weldments of 100 Ksi Yield Strength Steel

6.0 PHASE IV - WELDING ASTM A71O GRADE A, CLASS 3, MODIFLED TO 100 Km YIELD STRENGTR ‘TO 5-1/4-121CH TRICK

6.1 Objectives of Phase IV. The continuation of qualifying HSLA A710 Class 3 (modified) material with 100 ksi minimum yield in thicknesses from 3-1/4 inches through 5-1/4 inches, using various welding processes to the specification requirements of MIL-STD-248C for HY1OO material concluded this project’s studies and testing of A71O material. The objective of this phase was to demonstrate whether or not the A71O, Claaa 3, material could equal or exceed typical values required of HY1OO, and therefore be considered as a substitute steel in areas such as ship decks, shear strake, hull and bulkhead applications where HY1OO is currently used.

6.2 Weld Joint Designs, Parameters, Test Results, Macro, and Micros tructures of Welds. The detailed procedure tests, results, and equipment used in this phase are given in Appendices A and B.

Addendum (added to guide the reader to appendices and figures developed in welding and testing the 100 ksi HSLA SteelS)

Appendix A, pages A-29 through A-104, provide the unabstracted data produced by Phase IV of this project. For each plate thickness - 3-1 /4 inches, 4-1/4 inches, 4-3/4 inches and 5-114 inches and for each weld process used, a joint sketch is provided that gives bevel angles, rOOt Ope~gs, consumable identity, weld process, weld pass sequences, electrical parameters and/for total heat input values and other details of the test assemblies. (See Figure 14.) Following each joint sketch are laboratory test data reports on tensiles, yield strength, location of fractures and test methods. Chsrpy V-notch test reports provide results for, each sample and an evaluation of shear versus brittle mode failure. (See Figure 15.)

WELD JOINT DESIGN

PHASE IV

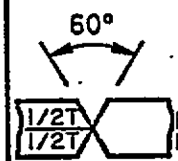
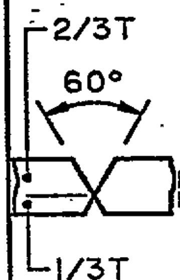
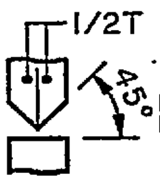
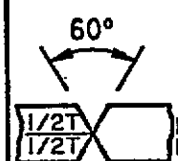
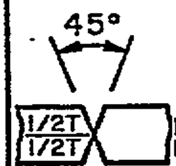
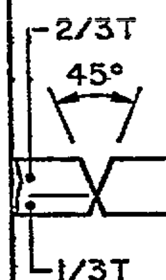
PL#	THK.	PROCESS	JOINT DESIGN
1	3 1/4"	SMAW	 R.O. 1/8" R.F. 1/4"
2	3 1/4"	SAW	 R.O. 0" R.F. 1/4"
3	3 3/4"	GMAW	 R.O. 1/8" R.F. 0"
4	3 3/4"	SAW	 R.O. 0" R.F. 1/4"
5	4 1/4"	SAW (NARROW GAP)	 R.O. 7/8 GAP AT TOP 1 3/16"
6	4 1/4"	SAW	 R.O. 0" R.F. 1/4"
7	4 3/4"	SAW (NARROW GAP)	 R.O. 7/8" GAP AT TOP 1 1/4"
8	4 3/4"	SAW	 R.O. 0" R.F. 1/4"
9	5 1/4"	SAW (NARROW GAP)	 R.O. 7/8" GAP AT TOP 1 5/16"
10	5 1/4"	SAW	 R.O. 0" R.F. 3/4"

Figure 14. Weld Joint Designs and Weld Processes For 3-1/4-Inch to 5-1/4-Inch Thick, 100 Ksi Yield Strength Modified ASTM A710, Grade A, Class 3

PHASE IV RESULTS

THICK-NESS	PROCESS AND CONSUMMABLES	KJ/IN INPUT	ALL WELD METAL Y.P.	T.S.	%E	REDUCED SECTION %RA	Y.P.	T.S.	*CHARPYS AT -60°F W	1 MM	5 MM
3 1/4	SMAW-E12018M ALLOY RODS	62	129	138	20	60	108	118	32	117	90
3 1/4	SAW-TANDEM DC LEADS AC TRAIL	198	81	107	24	65	99	114	19	28	157
3 3/4	GMAW-LTECH 120 W/98%A	61	132	139	19	63	118	124	55	141	120
3 3/4	SAW-TANDEM DC LEAD AC TRAIL	198	90	108	25	58	105	111	20	158	107
4 1/4	SAW-DC NARROW GAP	89	102	111	25	64	102	114	12.6	197	112
4 1/4	SAW-TANDEM DC LEAD AC TRAIL	204	88	108	24	65	98	113	11.2	107	47
4 3/4	SAW-DC NARROW GAP	83	105	112	23	64	106	118	21	141	67
4 3/4	SAW DC LEAD AC TRAIL	162	90	110	26	65	104	113	12.3	72	126
5 1/4	SAW-DC NARROW GAP	91	103	112	14	26	102	115	16	152	66
5 1/4	SAW DC LEAD AC TRAIL	162	80	110	25	65	91	110	15	96	107

***ALL CHARPY "V"S ARE TRANSVERSE**

Figure 15. Physical Properties Resulting from Various Weld Processes and Heat Inputs for 3-1/4 Inch to 5-1/4 Inch ASTM A710, Grade A, Class 3, Modified to 100 ksi Yield Strength

Heat affected zone testing of charpy V-notch toughness is given at -60 degrees F. For some test assemblies weld metal was retested at -40 degrees F, -20 degrees F, -10 degrees F and at O degrees F. (See Figure 16.)

A macroetch photo and microstructure are provided for the 3-3/4 inch mig weld; macros snd microstructure are given for the 4-1/4 inch, 4-3/4 inch and 5-1/4 inch sub-arc welds described in Appendix A, pages A-47 through A-89.

Some data relating to analyais of the low toughness values of the Phase IV weldments is available in the chemical analyses of veld deposits and weld wire and in the phone memorandum of J. West (Bethlehem) to Dave Mayer (LTEC), Appendix A, pages A-90 through A-98 . The metallurgical description of microstructure on page A-58 also applies.

Mill reports from Kawasaki Steel provide tensile, chemistry, impact test, hardness, heat treat schedules, and other base line data on the steel plates and are included on pages A-98 to A-104.

Addendum by O. J. Davis

6.3 Welding Processes and Consumables. Welding processes and consumables used in the final phase of this study included:

SMAW	E12018-M	Allow Rods "Atom Arc" Electrodes
GMAW	ER120S-1	L-Tee 120 Wire with 98 percent AR - 2 percent Oxy Shielding Gas
SAW	F11A6-EM4-M4	L-Tee 120 Wire with L-Tec 0091 Flux

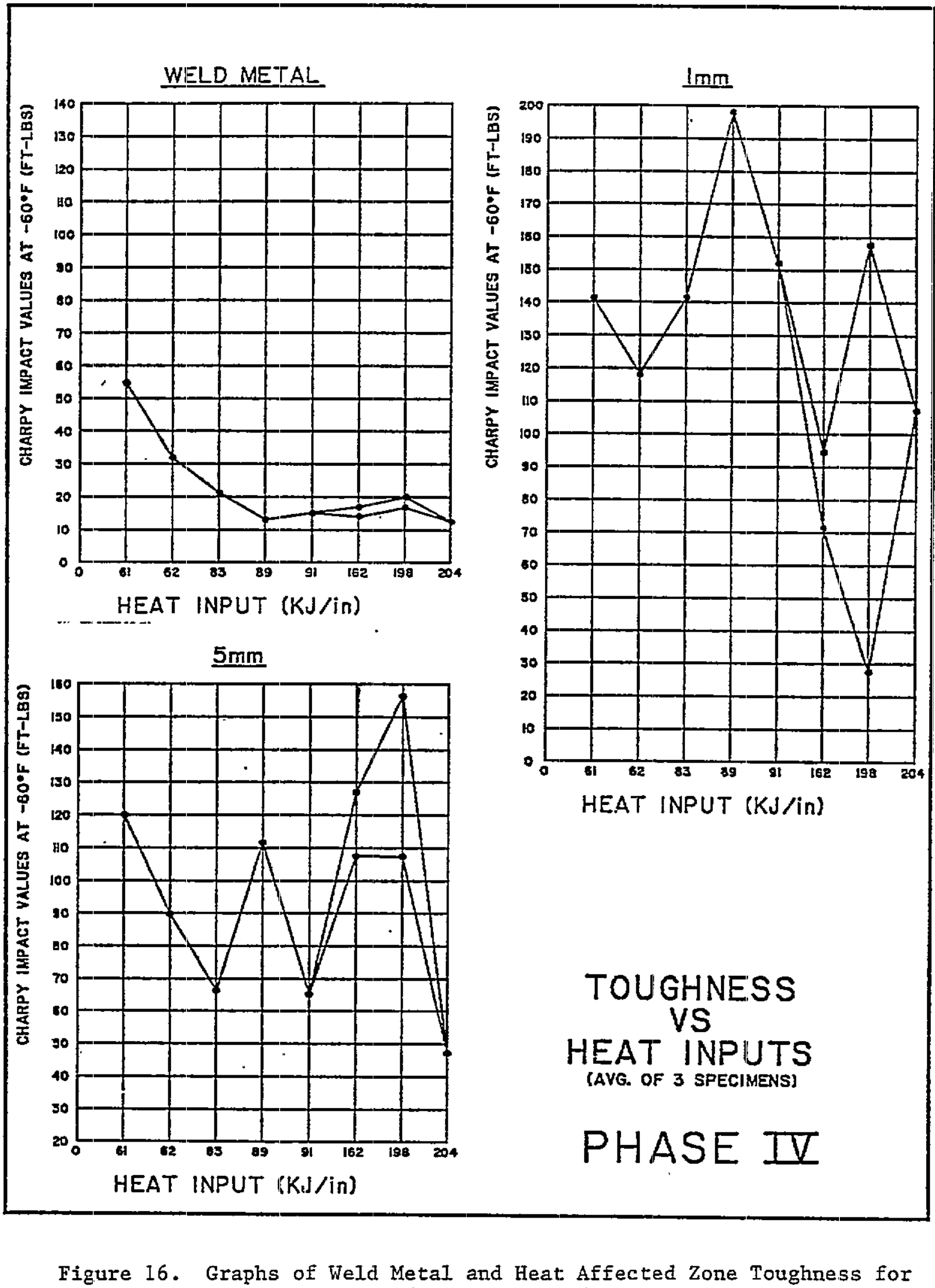


Figure 16. Graphs of Weld Metal and Heat Affected Zone Toughness for Weldments of 3-1/4-Inch to 5-1/4-Inch Thick, ASTM A710, Grade A, Class 3 Modified to 100 Ksi Yield Strength

6.4 Discussions of Welding Practice for 10 Test Plates. Ten (10) test plate assemblies were welded. Test plates were furnished in the quenched and precipitation hardened condition as described in Appendix A. Eight (8) of the ten (10) test plates were welded using the SAW process of which three (3) plates were jOined by the narrow gap technique. The other two (2) test plates were welded using the SMAW and GMAW process. Techniques used to fabricate plates were for the most part standard fill and cap, although, the tamper bead technique was performed on several teat plate assemblies. Preheat of test plates ranged from drying (approximately 125 degrees F) to 300 degrees F. Maximum interpass temperatures ranged from 400 degrees to 600 degrees F. The last three (3) test plates (Nos. 8, 9, and 10) were limited to 400 degrees F maximum. Joint restraint for all test plates was low.

6.5 Heat Inputs for Phase IV Plates. Heat inputs ranged from 61 KJ/in. (See Appendix A Joint Design Sheets.)

6.6 Drying of Flux For Sub-Arc. L-Tee 0091 Flux was dried at 250”F for 4 hours minimum, from sealed bag prior to use.

6.7 Moisture Control of SMAW Electrodes. Stick electrodes were used from freshly opened hermetically sealed containers or from electrode oven held at 250 degrees - 300 degrees F prior to use. All electrodes removed from oven or container were consumed within a 1/2 hour time frame.

7.0 PHASE IV RESULTS

a. Transverse Neld Metal Tension Tests exceeded 100 ksi minimum yield on seven (7) of the ten (10) test plates. The three (3) plates that failed to meet the 100 ksi minimum yield were welded using heat inputs over 160 KJ/in.

b. Neld Metal Tension Tests exceeded 100 ksi minimum yield only on test plates with heat inputs of 91 KJ/in. or less.

c. Charpy V-notch Weld Metal Impact Tests were acceptable only with the manual and semi-automatic welding processes. The higher heat inputs of the automatic welding process resulted in at best marginal CVN values.

d. Heat Affected Zone Charpy V-notch Impact Tests were excellent and generally met or exceeded unaffected base metal properties.

e. Arc blow problems began to manifest during sub arc welding of thicker plates. Rearranging or splitting the ground cable was not always successful in eliminating this problem. Neld bead profile and slag removal were undesirable under these conditions.

f. Nozzle alignment with weld groove is exacting using the narrow gap process, otherwise the contact nozzle would short out due to the insulation rubbing off on side wall of joint.

g. The air cooled MT-400 GMAN torch head O-rings would deteriorate under sustained use allowing air in gas line. This resulted in scattered and cluster porosity problems.

h. Submerged arc weld metal deposits of F11A6-EM4-M4 classification suffered significant core ingredient losses (eg. : Mn, Ni, Cr, Mo) while gaining appreciable amounts of Si. This undoubtedly accounted for the low upper shelf Charpy values in the weld metal

deposit. Further chemical analysis (Appendix A) of the FL 1A6-EM4-M4 wire-f lux combination used in this study revealed that both the core wire and weld deposit analysis did not meet the classification stated above. This aspect was confirmed with the manufacturer's representative (see phone memo attached) who when contacted indicated the classification of this wire-flux combination should have been listed under the SFA 5.23 :EG grouping. (See Figure 17 for CVN values.)

i. Micro structure analysis of several test plate specimens consistently revealed a fine dendritic grained ferrite and pearlite formation in the weld metal deposit. Only test plate No. 3 (GMAW) revealed a more desirable Widmanstatten ferrite platelets with some pearlite in the weld deposit.

j. Precipitate shown at grain boundaries are believed to be compounds of Fe, and Cr_3C_2 as observed in photomicrographs Numbers 4 and 6, and Phase IV test plates numbers 6 and 10 respectively.

PHASE IV

WELD CENTERLINE CHARPY VALUES AT VARIOUS TEMPERATURES

PLT #	THICK-NESS	KJ/IN INPUT	-60° F	-40° F	-20° F	-10° F	0° F
5	4 1/4"	89	12.6	23	28	39	
6	4 1/4"	204	11.2	21	42	51	
7	4 3/4"	83	21	23	27	38	
8	4 3/4"	162	12.3	28	20.5		52
9	5 1/4"	91	16	29	33		47
10	5 1/4"	162	15	19.3	30	27	

PLATES 6,7,10 - DUAL SAW - TWO SIDES

PLATES 5,7,9 - SINGLE SAW N.G. ONE SIDE ONLY

Figure 17. Weld Centerline Charpy Values at Various Temperatures

8.0 PHASE III AND IV COMMENTS AND CONCLUSIONS

a. The test results obtained in Phase 111 and IV indicated th2t excellent strength, toughness, and ductility is an inherent characteristic of A71O, Class 3 (modified) material. Charpy V-notch values in the coarse grained heat affected zone (HAZ) and the HAZ-weld metal interface was consistently superior to the weld metal deposits.

b. No occurrence of hydrogen induced HAZ cracking was observed in the 18 welded test plate assemblies. The low sensitivity to HAZ cracking of A71O, Class 3, modified makes this material an ideal candidate for use in areas where optimal welding conditions cannot be met. Additionally, significant cost reductions are realized through reduced preheat requirements, less stringent interpass temperature controls and reduced frequency of underbead or hydrogen-assist ed cracking problems.

c. The unique chemistry of A71O, Class 3, modified material provided excellent weldability with all of the commonly used welding processes.

d. Effects of high heat input welding (up to 230 KJ/in.) did not produce serious heat affected zone degradation, although, reduced heat input values are mandatory to yield acceptable charpy V-notch values in the weld metal deposit.

e. Continued development of welding consumables by the various manufacturers is required to prevent the weld metal deposit from becoming the limiting factor when selecting A71O, Class 3, modified material for use.

APPENDIX A

WELDING PARAMSTESR, TECRNIQDS ANO LABORATORY REPORTS

SUPPLEMENTRY DATA FOR PHASE 111 AND IV JOINT DESIGNS,

WELDING PARAMETERS , IRDEPENOSNT LABORATORY ANALYSIS REPORTS,

MACRO ANO MICROSTRUCTURES , WELD WIRE ANALYSIS STEEL MILL

CERTIFICATION TEST REPORTS

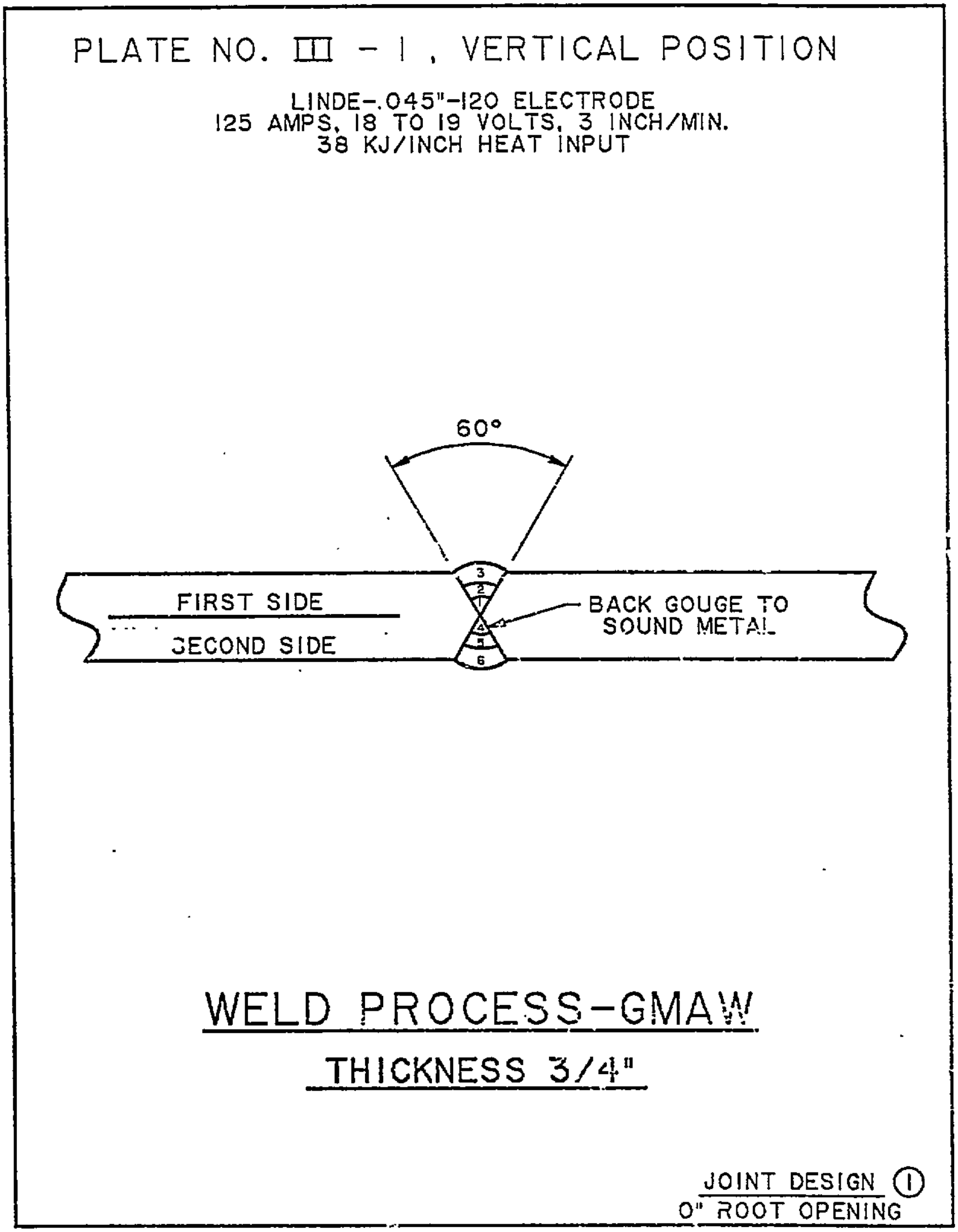


Figure A-1. ASTM A710 Modified to 100 Ksi Yield Strength

SOUTHWESTERN LABORATORIES

REPORT OF TESTS ON METAL SPECIMENS

FILE NO. 4092300

Beaumont TEXAS June 17, 1986

TO:	Bethlehem Steel Corporation	REPORT NO.	92764
PROJECT	Mechanical Testing of Welding Procedure	ORDER NO.	6939-006
MATERIAL	A-710, Gr. A, Cl.3 Modified, 3/4" Thickness		
IDENTIFICATION	Plate "1"		
SPEC. REFERENCE	ASME Sec. IX, SWL No. 9706-103-75, Rev. 1		

Specimen	Size	Sq. In. Area	Yield, p.s.i.*	Ultimate Strength, lbs.	Tensile Strength, p.s.i.	% El.	% R.A.	Location of Fracture
REQUIRED:								
T-1A	1.486 x .684	1.016	110,236	117,700	115,846			Parent Metal
T-1B	1.494 x .675	1.008	111,557	117,600	116,666			Parent Metal
T-2A	1.485 x .702	1.042	108,733	118,400	113,627			Parent Metal
T-2B	1.504 x .682	1.025	81,893	117,700	114,829			Parent Metal
T-3	.505" Dia.	.2003	111,083	25,030	124,962	16.5%	49%	

Side Bend #1 .... Satisfactory

Side Bend #2 .... Satisfactory

Side Bend #3 .... Satisfactory

Side Bend #4 .... Satisfactory

TECHNICIAN: John Blair

COPIES TO: 3-Bethlehem Steel Corp.
Attn: Mr. Todd Anderson

SOUTHWESTERN LABORATORIES

John B Blair

Figure A-2. Tensile and Bend Tests for Plate III-1

"241-D "

SOUTHWESTERN LABORATORIES

FORT WORTH DALLAS HOUSTON MIDLAND BEAUMONT TEXARKANA

FILE NO. 4092300

Beaumont TEXAS, June 17, 1986

IMPACT TESTS ON STEEL

To: Bethlehem Steel Corporation

P. O. No. 6939-006 Date of Test 6-11-86

Material: A-710, Gr. A, Cl.3 Modified, 3/4" Thickness

Identification Marks: Plate "1"

Specifications: ASTM A-370, SWL No. 9706-102-75, Rev. 2

Testing Machine: T.O. Ser. #8440 Test Method: "V" Notch Simple Beam Charpy

Linear Velocity of Hammer: 16.8 ft. per second

Effective Energy: 264 ft. pounds Specimen Type: "A"

Specimen Size: 10mm x 10mm Specimen Temp: Minus 60°F

Identification	Width, In Inches	Effective Section Size, In Inches	Impact Value Ft. Lbs.	Lateral Exp. Mills	% Shear
Weld #1	.395	.315	66	26	40
Weld #2	.394	.315	77	32	40
Weld #3	.395	.315	63	25	40
Weld #4	.395	.315	69	30	40
Weld #5	.394	.315	71	28	40
Fusion Line					
+1mm #1	.394	.315	95	45	70
#2	.394	.315	96	46	70
#3	.395	.316	94	50	70
#4	.394	.315	97	51	70
#5	.394	.315	97	47	70
Fusion Line					
+5mm #1	.395	.315	88	45	70
#2	.394	.315	79	35	50
#3	.395	.315	79	34	50
#4	.395	.315	96	46	70
#5	.395	.315	73	34	60

Copies: 3-Bethlehem Steel Corporation
Attn: Mr. Todd Anderson

SOUTHWESTERN LABORATORIES

PER John B. Blair

Lab. No. 92777mm

Figure A-3. Impact Tests at - 60 Degrees F for Plate III-1

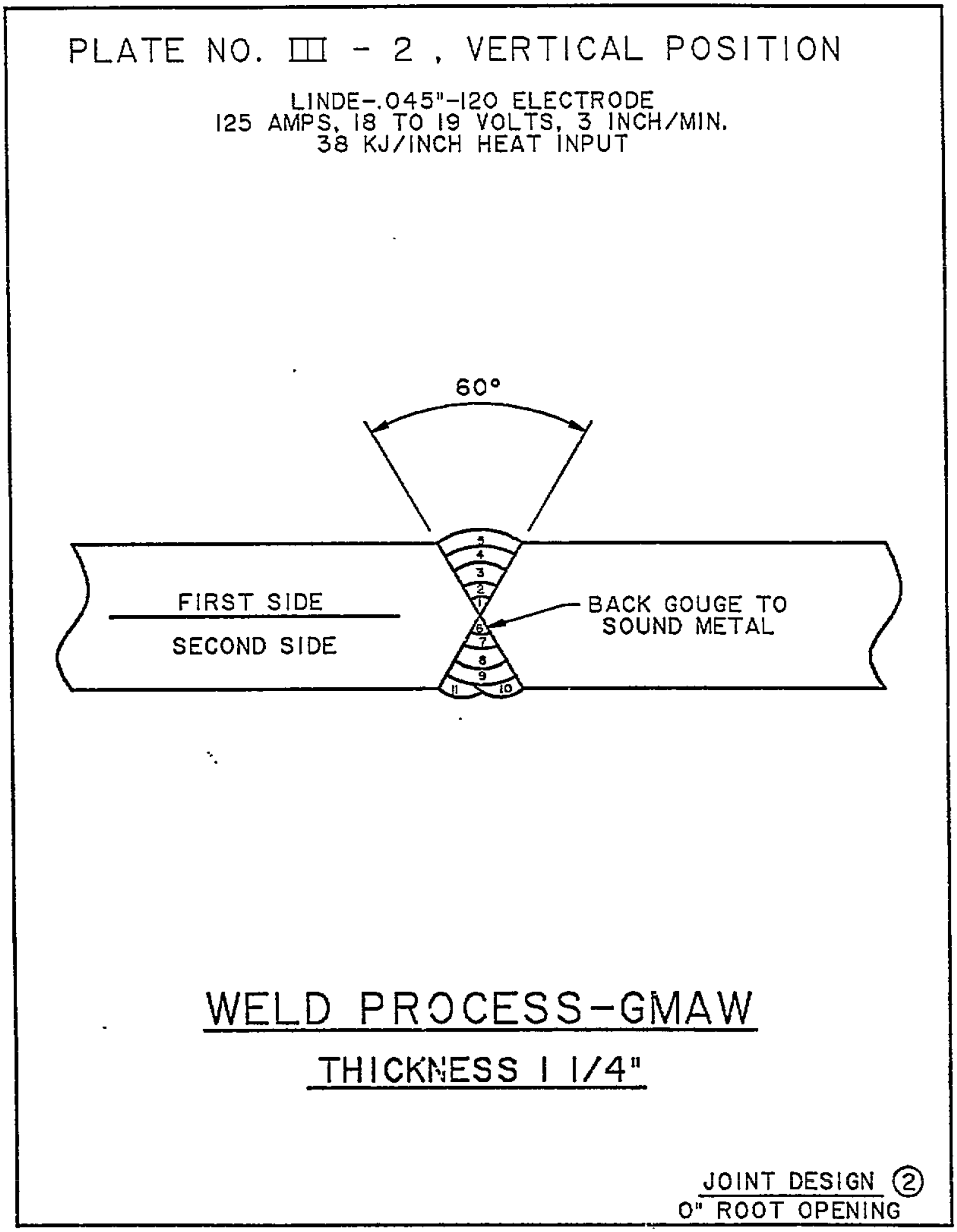


Figure A-4. SMAW Weld of 1-1/4-Inch Thick 100 ksi Yield Strength Steel

SOUTHWESTERN LABORATORIES

REPORT OF TESTS ON METAL SPECIMENS

FILE NO. 4092300

Beaumont TEXAS June 17, 1986

TO:	Bethlehem Steel Corporation	REPORT NO.	92765mm
PROJECT	Mechanical Testing of Welding Procedure	ORDER NO.	6939-006
MATERIAL	A-710, Gr. A, Cl.3 Modified, 1-1/4" Thickness		
IDENTIFICATION	Plate "2"		
SPEC. REFERENCE	ASME Sec. IX, SWL No. 9706-103-75, Rev. 1		

Specimen	Size	Sq. In. Area	Yield, p.s.i.*	Ultimate Strength, lbs.	Tensile Strength, p.s.i.	% El.	% R.A.	Location of Fracture
REQUIRED:								
T-1A	1.508 x .596	.8987	111,152	107,900	120,053			Parent Metal
T-1B	1.503 x .552	.8296	114,023	98,700	118,964			Fusion Line
T-2A	1.526 x .517	.7889	112,809	94,700	120,034			Parent Metal
T-2B	1.528 x .625	.955	117,986	116,300	121,780			Parent Metal
T-3	.497" Dia.	.1940	127,319	25,380	130,824	11.5%	37.4%	

Side Bend #1 .... Satisfactory

Side Bend #2 .... Unsatisfactory

Side Bend #3 .... Satisfactory

Side Bend #4 .... Unsatisfactory

TECHNICIAN: John Blair

CCPIES TO: 3-Bethlehem Steel Corporation
Attn: Mr. Todd Anderson

SOUTHWESTERN LABORATORIES

John B. Blair

Figure A-5. Tensile and Bend Tests for Plate III-2

241-D

SOUTHWESTERN LABORATORIES

FORT WORTH DALLAS HOUSTON MIDLAND BEAUMONT TEXARKANA

FILE NO. 4092300

Beaumont, TEXAS June 17, 1986

IMPACT TESTS ON STEEL

To: Bethlehem Steel Corporation

P. O. No. 6939-006 Date of Test 6-11-86

Material A-710, Gr. A, Cl.3 Modified, 1-1/4" Thickness

Identification Marks Plate "2"

Specifications ASTM A-370, SWL No. 9706-102-75, Rev. 2

Testing Machine: T.O. Ser. #8440 Test Method: "V" Notch Simple Beam Charpy
Linear Velocity of Hammer: 16.8 ft. per second
Effective Energy: 264 ft. pounds Specimen Type: "A"
Specimen Size: 10mm x 10mm Specimen Temp: Minus 60°F

Specimen Identification	Width, In Inches	Effective Section Size, In Inches	Impact Value Ft. Lbs.	Lateral Exp. Mills	% Shear
Weld #1	.395	.315	71	24	60
Weld #2	.394	.315	57	20	40
Weld #3	.395	.315	78	34	60
Weld #4	.394	.315	72	29	70
Weld #5	.395	.315	76	30	70
Fusion Line					
+1mm #1	.394	.315	70	28	40
#2	.394	.315	80	40	40
#3	.394	.315	73	36	40
#4	.394	.315	62	28	40
#5	.394	.315	77	38	50
Fusion Line					
+5mm #1	.394	.315	68	30	40
#2	.394	.315	62	25	30
#3	.395	.315	68	32	40
#4	.394	.315	49	19	30
#5	.395	.315	61	30	30

Copies: 3-Bethlehem Steel Corporation
Attn: Mr. Todd Anderson

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PER John B. Blair

Lab. No. 92778mm

Figure A-6. Impact Tests at - 60 Degrees F for Plate III-2

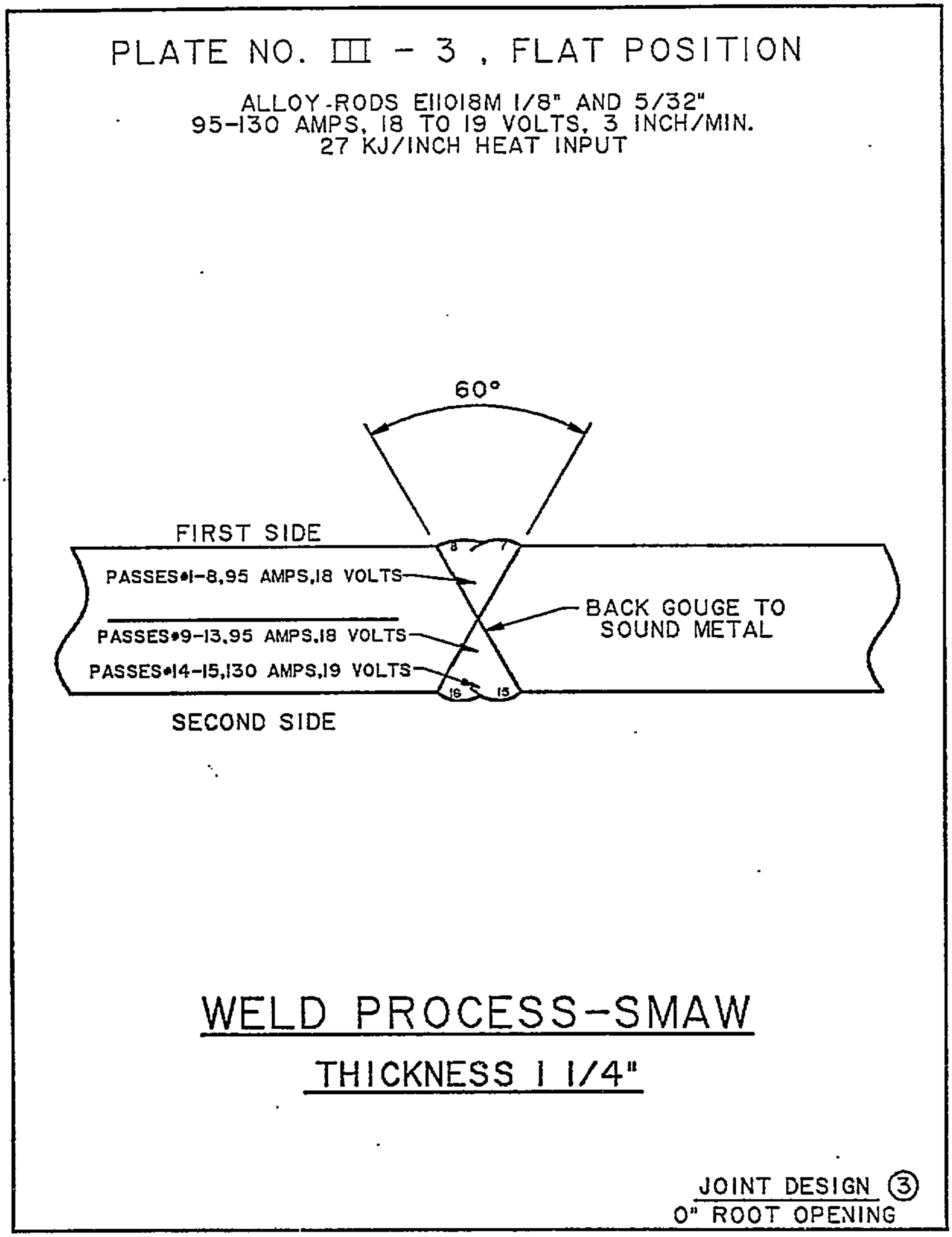

Figure A-7. Weld Test Assembly for SMAW Weld
of 1-1/4-Inch Thick 100 ksi Yield Strength Steel

SOUTHWESTERN LABORATORIES

REPORT OF TESTS ON METAL SPECIMENS

FILE NO. 4092300

Beaumont TEXAS 7/8/86

REPORT NO. 92795-cr

ORDER NO. 6939-006

TO: Bethlehem Steel Corporation

PROJECT Mechanical Testing of Welding Procedure

MATERIAL A-710 Grade A Class 3 Modified, 1-1/4" TK

IDENTIFICATION Plate #3

SPEC. REFERENCE ASME Sec. IX, SWL No. 9706-103-75 Rev. 1

Specimen	Size	Sq. In. Area	Yield, p.s.i.*	Ultimate Strength, lbs.	Tensile Strength, p.s.i.	% El.	% R.A.	Location of Fracture
REQUIRED:								
T-1 A	1.477x.618	.9127	110,102	105,700	115,799			Weld Metal
T-1 B	1.505x.563	.8473	105,037	96,200	113,535			Weld Metal
T-2A	1.484x.539	.7998	112,517	94,700	118,393			Weld Metal
T-2B	1.526x.658	1.00	111,541	118,200	117,716			Parent Metal
T-3 (all weld)	.505" Dia.	.2003	124,812	24,990	124,762	N/A	N/A	*

Side Bend #1 - UnSatisfactory

Side Bend #2 - UnSatisfactory

Side Bend #3 - UnSatisfactory

Side Bend #4 - UnSatisfactory

* Fracture Outside of Gauge Marks

TECHNICIAN: John Blair

COPIES TO: 3-Todd Anderson

SOUTHWESTERN LABORATORIES

John B. Blair

Figure A-8. Tensile and Bend Tests for Plate III-3

241-D

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JUL 15 1986
ENGINEERING DEPT.

SOUTHWESTERN LABORATORIES

FORT WORTH DALLAS HOUSTON MIDLAND BEAUMONT TEXARKANA

FILE No. 4092300

Beaumont, TEXAS 7/9/86

IMPACT TESTS ON STEEL

To Bethlehem Steel Corporation

P. O. No. 6939-006 Date of Test 6/11/86

Material A-710 Gr. A, Cl.3 Modified, 1-1/4" TK

Identification Marks Plate 3

Specifications ASTM A-370, SWL No. 9706-102-75 Rev. 2

Testing Machine: T.O. Ser.# 88440 Test Method: "V" Notch Simple Beam Charpy
Linear Velocity of Hammer: 16.8 ft. per second
Effective Energy: 264 ft. pounds Specimen Type: "A"
Specimen Size: 10mm x 10mm Specimen Temp: Minus 60°F

Specimen Identification		Width, In Inches	Effective Section Size, In Inches	Impact Value Ft. Lbs.	Lateral Exp. Mills	% Shear
Weld	#1	.395	.315	26.0	8.0	20
	2	.395	.315	35.0	11.0	20
	3	.395	.315	16.0	1.0	20
	4	.395	.315	18.5	11.0	20
	5	.395	.315	27.0	8.0	20
Fusion Line	1	.395	.315	79.0	33.0	60
+1mm	2	.395	.315	70.0	34.0	50
	3	.395	.315	55.0	25.0	40
	4	.395	.315	69.0	32.0	40
	5	.395	.315	53.0	24.0	40
Fusion Line	1	.395	.315	57.0	25.0	40
+5mm	2	.395	.315	65.0	35.0	40
	3	.395	.315	59.0	28.0	40
	4	.395	.315	63.0	28.0	40
	5	.395	.315	60.0	28.0	40

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PER John B. Blair

Lab. No. 92822-cr

Figure A-9. Impact Tests for Plate III-3

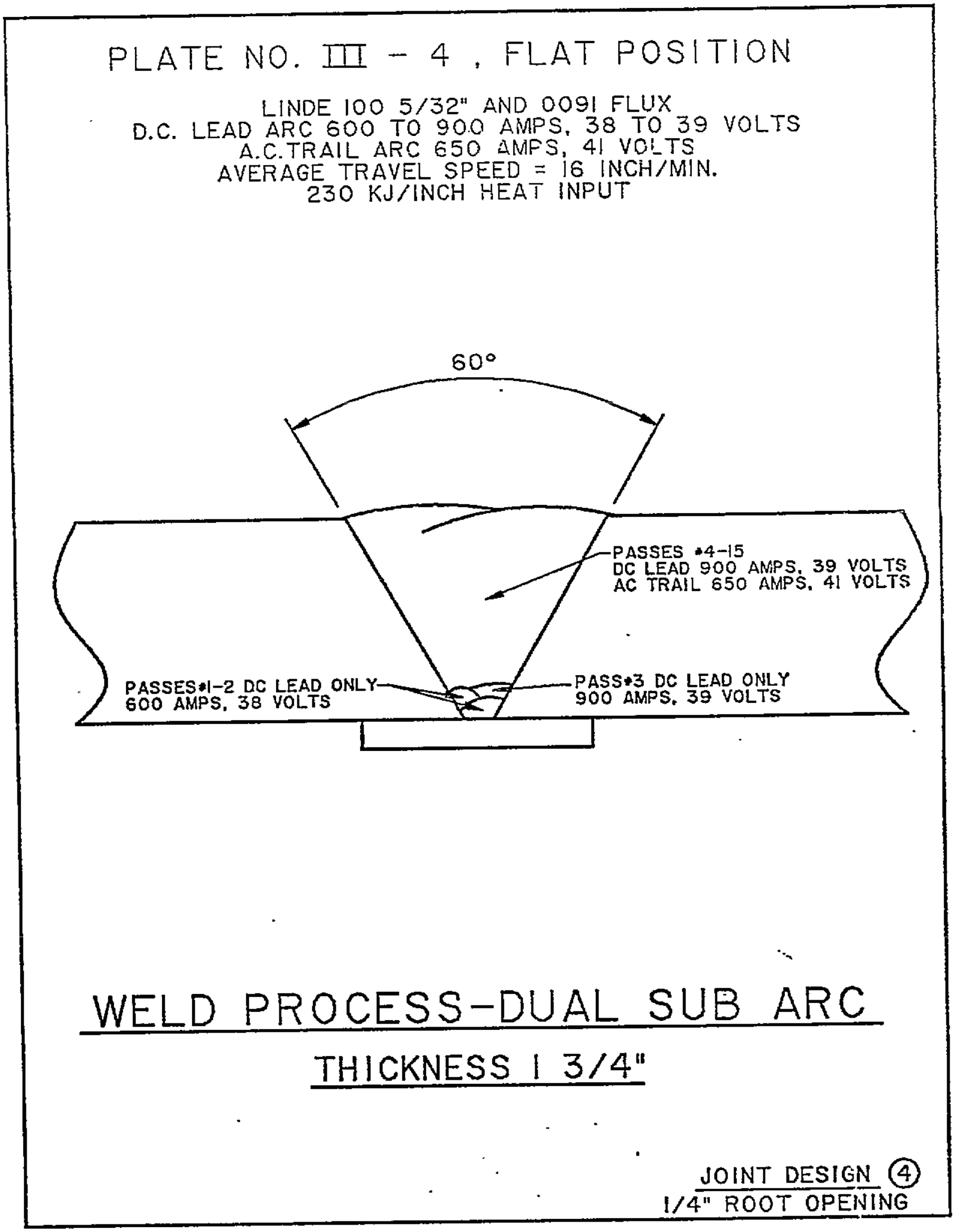

Figure A-10. Sub Arc Weld Test Assembly for 1-3/4-Inch Thick 100 ksi Yield Strength Plate

SOUTHWESTERN LABORATORIES

REPORT OF TESTS ON METAL SPECIMENS

FILE NO. 4092300

Beaumont TEXAS 7/8/86

TO:	Bethlehem Steel Corporation	REPORT NO.	92794-cr
PROJECT	Mechanical Testing of Welding Procedure	ORDER NO.	6939-006
MATERIAL	A-710 Grade A Class 3 Modified, 1-3/4" TK		
IDENTIFICATION	Plate 4		
SPEC. REFERENCE	ASME Sec. IX, SWL No. 9706-103-75 Rev. 1		

Specimen	Size	Sq. In. Area	Yield, p.s.i.*	Ultimate Strength, lbs.	Tensile Strength, p.s.i.	% El.	% R.A.	Location of Fracture
REQUIRED:								
T-1A	1.531x.797	1.22	103,834	137,300	112,521			Parent Metal
T-1B	1.512x.844	1.27	76,402	146,000	114,408			Parent Metal
T-2A	1.471x.892	1.31	74,687*	144,800	110,354			Parent Metal
T-2B	1.476x.801	1.18	103,190	129,600	109,619			Parent Metal
	Side Bend #1 - Satisfactory							
	Side Bend #2 - Satisfactory							
	Side Bend #3 - Satisfactory							
	Side Bend #4 - Satisfactory							
T-3	.507" dia.	.2019	86,676	24,260	120,158	23%	51%	

* Fracture Outside of Gauge Marks

TECHNICIAN: John Blair

COPIES TO: 3-Todd Anderson

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John B. Blair

Figure A-11. Tensile and Bend Tests for Plate III-4

241-D

SOUTHWESTERN LABORATORIES

FORT WORTH DALLAS HOUSTON MIDLAND BEAUMONT TEXARKANA

FILE NO. 4092300

Beaumont TEXAS 7/8/86

IMPACT TESTS ON STEEL

To Bethlehem Steel Corporation

P. O. No. 6939-006 Date of Test 7/7/86

Material A-710, Gr. A, Cl.3 Modified, 1-3/4" TK

Identification Marks Plate 4

Specifications ASTM A-370, SWL No. 9706-102-75 Rev. 2

Testing Machine: T.O. Ser.# 88440 Test Method: "V" Notch Simple Beam Charpy

Linear Velocity of Hammer: 16.8 ft. per second

Effective Energy: 264 ft. pounds Specimen Type: "A"

Specimen Size: 10mm x 10mm Specimen Temp: Minus 60°F

* Minus 120°F

Specimen Identification		Width, In Inches	Effective Section Size, In Inches	Impact Value Ft. Lbs.	Lateral Exp. Mills	% Shear
Weld	#1	.395	.315	14.0	2.0	20
	2	.395	.315	14.0	1.0	20
	3	.395	.315	16.5	3.0	20
	4	.395	.315	17.0	3.0	20
	5	.395	.315	18.0	4.0	20
	* 6	.395	.315	7.5	0	10
	* 7	.395	.315	7.0	0	10
	* 8	.395	.315	9.0	0	10
	* 9	.394	.315	6.5	0	10
	*10	.395	.315	6.0	0	10
Fusion	#1	.395	.315	44.0	20.0	10
	2	.395	.315	47.0	23.0	10
	3	.395	.315	48.0	23.0	10
	4	.395	.315	72.0	35.0	20
	5	.395	.315	63.0	33.0	20
	* 6	.395	.315	31.0	11.0	10
	* 7	.395	.315	13.0	0	10
	* 8	.395	.315	49.0	26.0	10
	* 9	.395	.315	17.0	2.0	10
	*10	.395	.315	38.0	16.0	10

Copies:

3-Todd Anderson

SOUTHWESTERN LABORATORIES

PER John B. Blair

Lab. No.

92824-cr

Figure A-12. Impact Tests at -60 Degrees F and -120 Degrees F for Plate III-4 (Sheet 1 of 2)

241-D

SOUTHWESTERN LABORATORIES

FORT WORTH DALLAS HOUSTON MIDLAND BEAUMONT TEXARKANA

FILE NO. 4092300

Beaumont TEXAS 7/9/86

IMPACT TESTS ON STEEL

To Bethlehem Steel Corporation

P. O. No. 6939-006 Date of Test

Material A-710 Gr. A, Cl.3 Modified, 1-3/4" TK

Identification Marks Plate 4

Specifications ASTM A-370, SWL No. 9706-102-75 Rev. 2

Testing Machine: T.O. Ser.# 88440 Test Method: "V" Notch Simple Beam Charpy
Linear Velocity of Hammer: 16.8 ft. per second
Effective Energy: 264 ft. pounds Specimen Type: "A"
Specimen Size: 10mm x 10mm Specimen Temp: Minus 60°F
*Minus 120°F

Specimen Identification		Width, In Inches	Effective Section Size, In Inches	Impact Value Ft. Lbs.	Lateral Exp. Mills	% Shear
Fusion Line	#1	.395	.315	78.0	40.0	40
+5mm	2	.395	.315	70.0	32.0	40
	3	.395	.315	85.0	45.0	40
	4	.395	.315	77.0	37.0	40
	5	.395	.315	69.0	27.0	40
Plate	* #1	.395	.315	15.5	2.0	10
	* 2	.394	.315	23.0	9.0	10
	* 3	.395	.315	11.0	9.0	10
	* 4	.395	.315	7.0	0	10
	* 5	.395	.315	11.0	0	10

Copies: 3-Bethlehem Steel Corporation
Attn: Todd Anderson

SOUTHWESTERN LABORATORIES

PER John B. Blair

Lab. No. 92823-cr

Figure A-12. Impact Tests at -60 Degrees F and -120 Degrees F for Plate III-4 (Sheet 2 of 2)

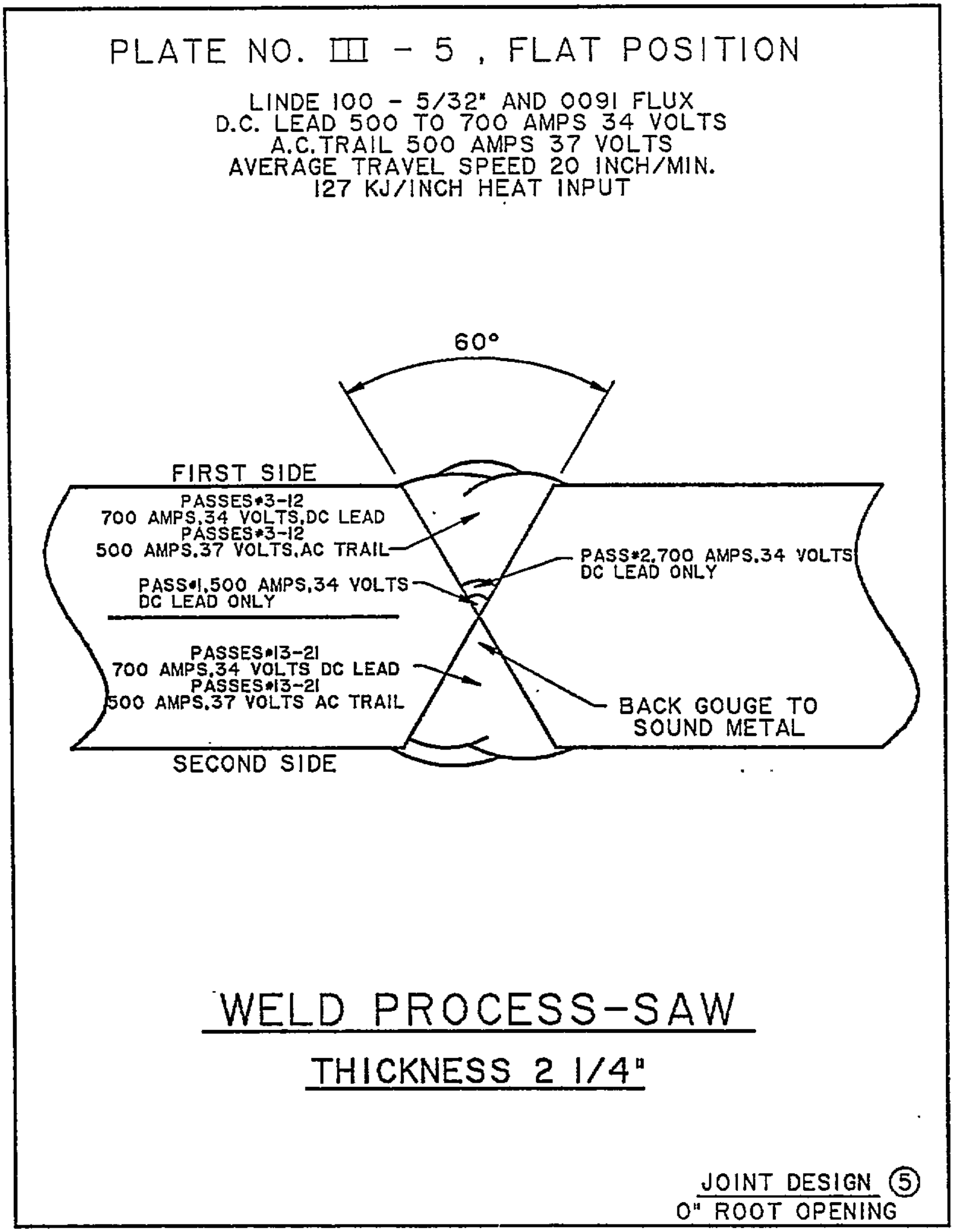

Figure A-13. Dual Sub-Arc Weld Test Assembly for 2-1/4-Inch Thick 100 ksi Yield Strength Steel Plate

SOUTHWESTERN LABORATORIES

REPORT OF TESTS ON METAL SPECIMENS

FILE NO. 4092300

Beaumont TEXAS 8/14/86

TO:	Bethlehem Steel Corporation	REPORT NO.	92902-cr
PROJECT	Mechanical Testing of Welding Procedure	ORDER NO.	6939-006
MATERIAL	A-710, Cl.3 Modified, 2-1/4" TK		
IDENTIFICATION	Plate "5"		
SPEC. REFERENCE	ASME Sec. IX, SWL No. 9706-103-75 Rev. 1		

Specimen	Size	Sq. In. Area	Yield, p.s.i.*	Ultimate Strength, lbs.	Tensile Strength, p.s.i.	% El.	% R.A.	Location of Fracture
REQUIRED:								
T-1A	1.521x.901	1.370	108,360	157,700	115,074			Parent Metal
T-1B	1.485x.663	.9845	100,654	107,400	109,084			Weld Metal
T-2A	1.492x.781	1.165	102,038	127,800	109,675			Parent Metal
T-2B	1.502x.803	1.206	99,327	131,700	109,194			Parent Metal
T-3 (all weld)	.509" Dia.	.2035	97,297	22,990	112,972	23	64	

Side Bend #1 - Satisfactory

Side Bend #2 - Satisfactory

Side Bend #3 - Satisfactory

Side Bend #4 - Satisfactory

TECHNICIAN: John Blair

COPIES TO: 3-Todd Anderson

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Jack W. Terrell

Figure A-14. Tensile and Bend Tests for Plate III-5

244-0

SOUTHWESTERN LABORATORIES

FORT WORTH DALLAS HOUSTON MIDLAND BEAUMONT TEXARKANA

FILE NO. 4092300

Beaumont TEXAS 8/20/86

IMPACT TESTS ON STEEL

To Bethlehem Steel Corporation

P. O. No. 6939-006 Date of Test 8/14/86

Material A-710 Cl.3 Modified, 2-1/4" TK

Identification Marks Plate 5

Specifications ASTM A-370, SWL No. 9706-102-75 Rev. 2

Testing Machine: T.O. Ser.# 88440 Test Method: "V" Notch Simple Beam Charpy
Linear Velocity of Hammer: 16.8 ft. per second
Effective Energy: 264 ft. pounds Specimen Type: "A"
Specimen Size: 10mm x 10mm Specimen Temp: Minus 60°F

Specimen Identification		Width, In Inches	Effective Section Size, In Inches	Impact Value Ft. Lbs.	Lateral Exp. Mills	% Shear
Weld	#1	.393	.315	19.0	5	30
	2	.393	.315	26.0	8	30
	3	.393	.315	47.0	21	30
	4	.394	.315	47.0	18	30
	5	.393	.315	21.0	7	30
Fusion Line	#1	.394	.315	51.0	26	20
+1mm	2	.394	.315	56.0	27	20
	3	.394	.315	63.0	31	20
	4	.393	.315	52.0	23	30
	5	.393	.315	53.0	28	20
Fusion Line	#1	.394	.315	49.0	24	20
+5mm	2	.394	.315	49.0	24	20
	3	.394	.315	53.0	24	20
	4	.393	.315	60.0	29	20
	5	.394	.315	39.0	19	20

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PER Jack R. Terrell

Lab. No. 92875-cr

Figure A-15. Impact Tests for Plate III-5 at -60 Degrees F

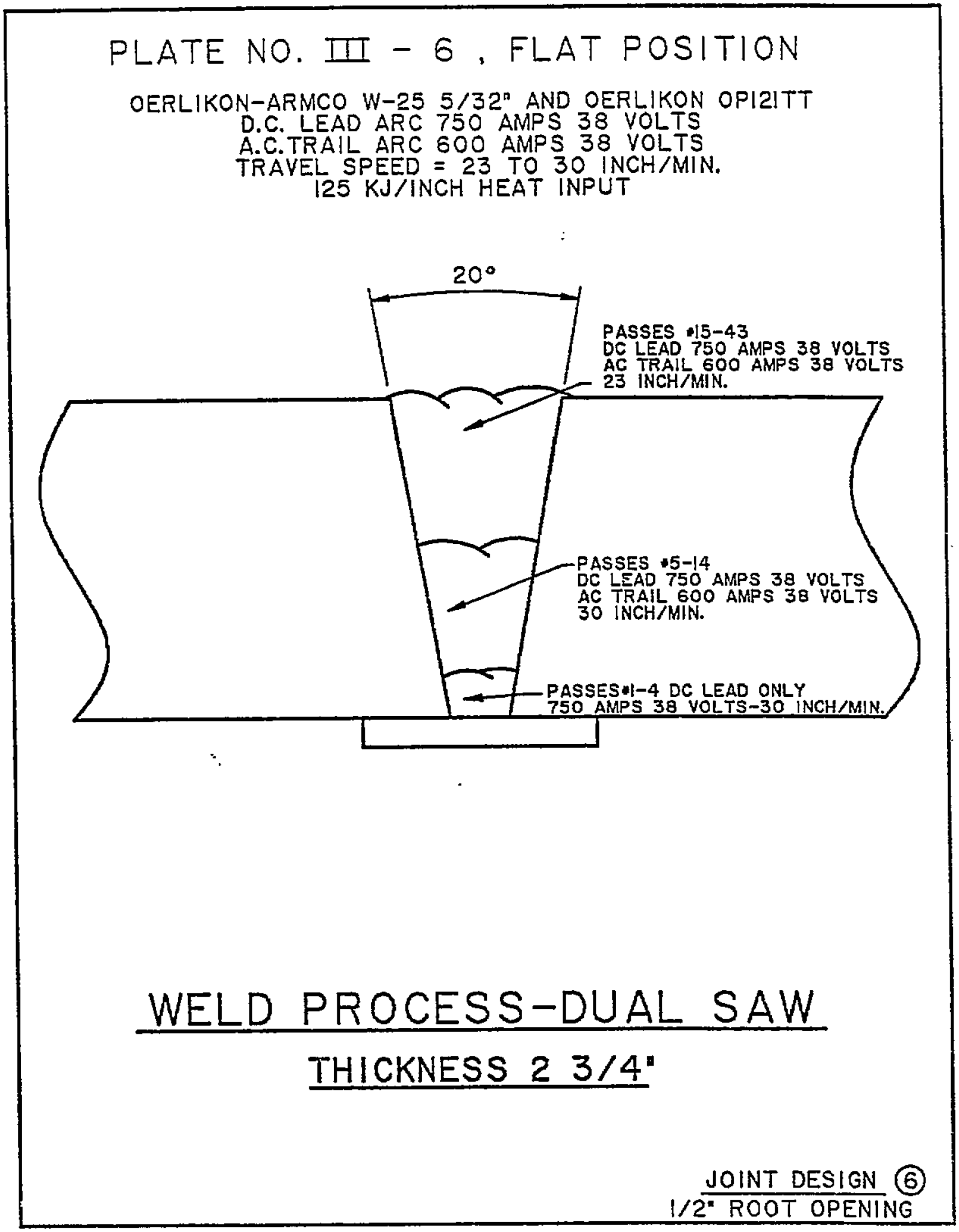

Figure A-16. Weld Test Assembly for 2-3/4-Inch Thick
100 ksi Yield Strength Steel Plate

SOUTHWESTERN LABORATORIES

REPORT OF TESTS ON METAL SPECIMENS

FILE NO. 4092300

Beaumont TEXAS 12-30-86

TO: Bethlehem Steel Corporation

REPORT NO. 93241-je

PROJECT Mechanical Testing of Welding Procedure

ORDER NO. 6939-006 Phase III

MATERIAL A-710 Cl.3 Modified, 2-3/4" tk.

IDENTIFICATION Plate 6

SPEC. REFERENCE ASME Sec. IX, SWL No. 9706-103-75 Rev. 1

Specimen	Size	Sq. In. Area	Yield, p.s.i.*	Ultimate Strength, lbs.	Tensile Strength, p.s.i.	% El.	% R.A.	Location of Fracture
REQUIRED:								
T-1	1.461 x .731	1.041	101,181	116,900	112,221			Weld Metal
T-2	1.460 x .753	1.099	98,691	117,700	107,060			Parent Metal

Side Bend #1 - Unsatisfactory

Side Bend #2 - Unsatisfactory

Side Bend #3 - Satisfactory

Side Bend #4 - Satisfactory

TECHNICIAN: John Blair

COPIES TO: Todd Anderson

SOUTHWESTERN LABORATORIES

John B. Blair

Figure A-17. Tensile and Bend Tests for Plate III-6

2M-D

SOUTHWESTERN LABORATORIES

FORT WORTH DALLAS HOUSTON MIDLAND BEAUMONT TEXARKANA

FILE No. 4092300

Beaumont TEXAS, 12/17/87

IMPACT TESTS ON STEEL

To: Bethlehem Steel Corporation

P. O. No. 6939-006 Phase III Date of Test 12/30/86

Material A-710 Cl.3 Modified, 2-3/4" tk.

Identification Marks Plate 6

Specifications ASTM A-370, SWL No. 9706-102-75 Rev. 2

Testing Machine: T.O. Ser. # 88440 Test Method: "V" Notch Simple Charpy

Linear Velocity of Hammer: 16.8 ft. per second

Effective Energy: 264 ft. pounds Specimen Type: "A"

Specimen Size: 10mm x 10mm Specimen Temp: Minus 40° F.

Specimen Identification	Width, In Inches	Effective Section Size, In Inches	Impact Value Ft. Pounds	Lateral Exp. Mills	% Shear
Weld #1	.394	.315	49	24	40
#2	.395	.315	45	26	50
#3	.394	.315	52	21	40
#4	.394	.315	47	13	50
#5	.394	.315	57	27	40
Fusion Line + 1 mm					
#1	.394	.315	84	49	50
#2	.394	.315	76	34	50
#3	.394	.315	24	16	10
#4	.394	.315	70	40	40
#5	.394	.315	75	42	20
Fusion Line + 5 mm					
#1	.394	.315	68	31	20
#2	.394	.315	68	37	20
#3	.394	.315	83	47	20
#4	.394	.315	62	32	20
#5	.394	.315	73	36	20

SOUTHWESTERN LABORATORIES

PER John B. Blair

Lab. No. 93234-je

Figure A-18. Impact Tests for Plate III-6 at -40 Degrees F

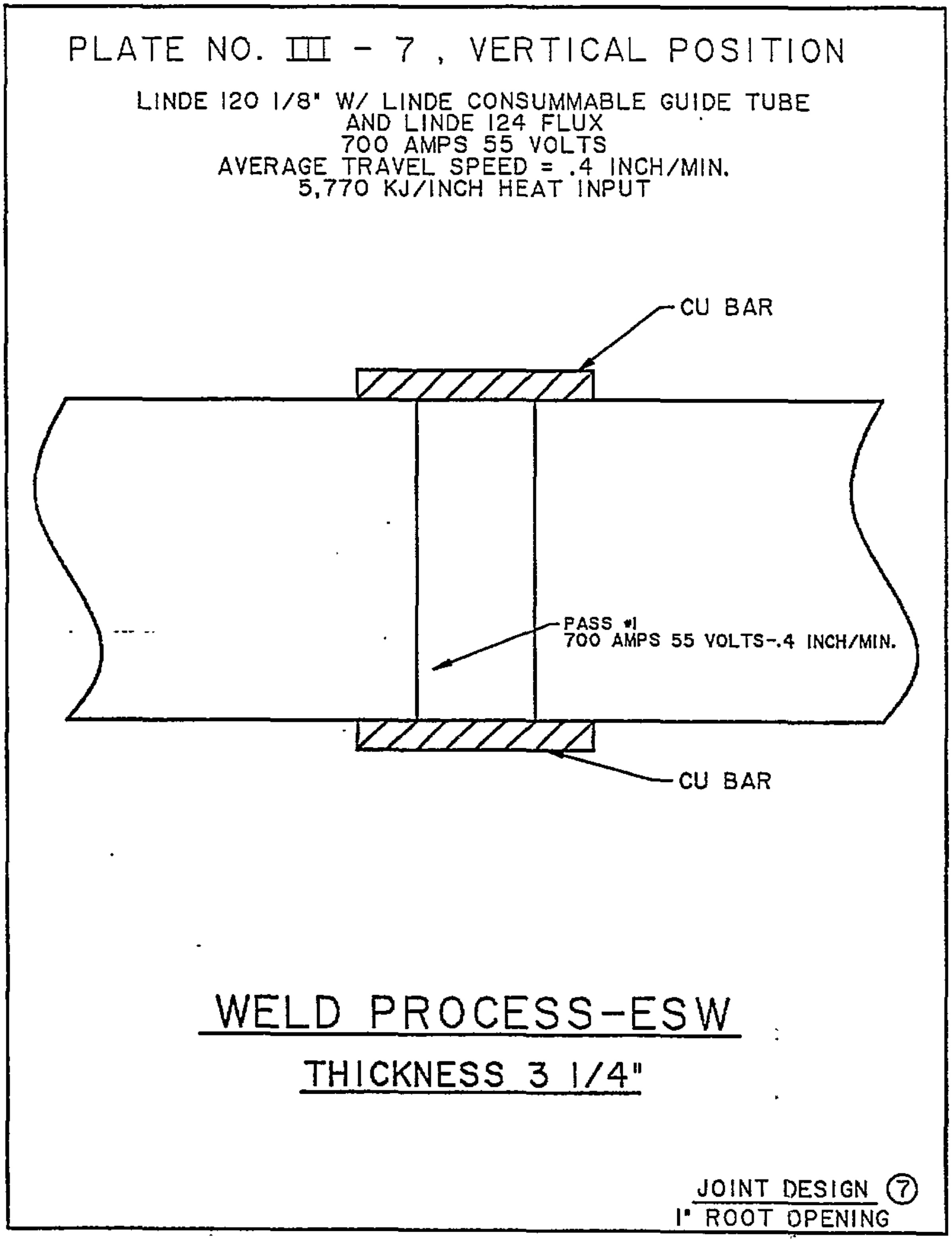

Figure A-19. Electroslag Weld Test Assembly for 3-1/4-Inch Thick 100 ksi Yield Strength Steel Plate

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REPORT OF TESTS ON METAL SPECIMENS

FILE NO. 4092300

Beaumont TEXAS 8/20/86

TO: Bethlehem Steel Corporation

REPORT NO. 92901-cr

PROJECT Mechanical Testing of Welding Procedure

ORDER NO. 6939-006

MATERIAL A-710 Cl.3 Modified, 3/4" TK

IDENTIFICATION Plate 7

SPEC. REFERENCE ASME Sec. IX, SWL No. 9706-103-75 Rev. 1

Specimen	Size	Sq. In. Area	Yield, p.s.i.*	Ultimate Strength, lbs.	Tensile Strength, p.s.i.	% El.	% R.A.	Location of Fracture
REQUIRED:								
T-1A	1.490 x .824	1.227	89,186	130,700	160,454			Weld Metal
T-1B	1.446 x .796	1.151	91,136	121,700	105,732			Weld Metal
T-2A	1.483 x .638	.9174	96,681	100,600	109,652			Weld Metal
T-2B	1.470 x .619	.9099	91,765	17,400	107,041			Weld Metal
T-3 (all weld)	.510" Dia.	.2043	67,058	21,760	106,510	15.5	34%	

Side Bend #1 - Satisfactory

Side Bend #2 - Satisfactory

Side Bend #3 - Satisfactory

Side Bend #4 - Satisfactory

TECHNICIAN: John Blair

COPIES TO: 3-Todd Anderson

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Figure A-20. Tensile and Bend Tests for Plate III-7

241-D

SOUTHWESTERN LABORATORIES

FORT WORTH DALLAS HOUSTON MIDLAND BEAUMONT TEXARKANA

FILE No. 4092300

Beaumont, TEXAS, 8/21/86

IMPACT TESTS ON STEEL

To Bethlehem Steel Corporation

P. O. No. 6939-006 Date of Test 8/14/86

Material A-710 Cl.3 Modified, 3-1/4" TK

Identification Marks Plate 7

Specifications ASTM A-370, SWL No. 9706-102-75 Rev. 2

Testing Machine: T.O. Ser.#88440 Test Method: "V" Notch Simple Charpy

Linear Velocity of Hammer: 16.8 ft. per second

Effective Energy: 264 ft. pounds Specimen Type: "A"

Specimen Size: 10mm x 10mm Specimen Temp: Minus 60°F

Specimen Identification		Width, In Inches	Effective Section Size, In Inches	Impact Value Ft. Lbs.	Lateral Exp. Mills	% Shear
Weld	#1	.394	.315	4.0	0	1
	2	.394	.315	7.5	0	1
	3	.394	.315	7.0	0	1
	4	.394	.315	8.5	0	1
	5	.394	.315	5.5	0	1
Fusion Line	#1	.394	.315	2.5	0	1
+1mm	2	.394	.315	4.0	0	1
	3	.394	.315	3.0	0	1
	4	.394	.315	4.5	0	1
	5	.394	.315	2.5	0	1
Fusion Line	#1	.394	.315	3.5	0	1
+5mm	2	.394	.315	5.5	0	1
	3	.394	.315	4.5	0	1
	4	.394	.315	10.0	0	1
	5	.394	.315	6.0	0	1

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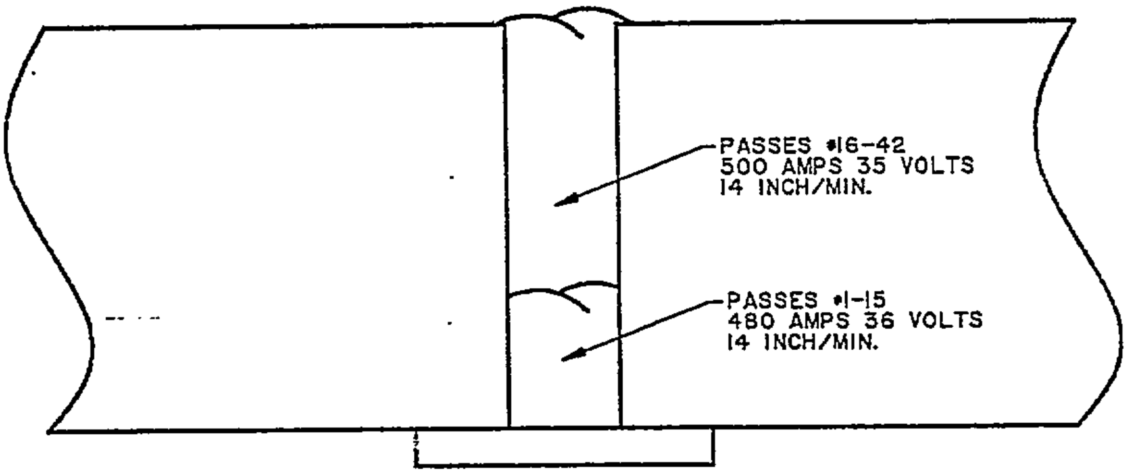
PER Jack W. Terrell

Lab. No. 92876-cr

Figure A-21. Impact Tests for Plate III-7 at -60 Degrees F

PLATE NO. III - 8 , FLAT POSITION

OERLIKON-ARMCO W-25 3/32" AND OERLIKON OP121TT
480 TO 500 AMPS 35 TO 36 VOLTS
AVERAGE TRAVEL SPEED = 14 INCH/MIN.
75 KJ/INCH HEAT INPUT



WELD PROCESS-SAW NG

THICKNESS 3 1/4"

JOINT DESIGN 8
3/4" ROOT OPENING

Figure A-22. Narrow Gap SubArc Weld Test Assembly for 3-1/4 Inch Thick 100 ksi Yield Strength Steel Plate

SOUTHWESTERN LABORATORIES

REPORT OF TESTS ON METAL SPECIMENS

FILE NO. 4092300

Beaumont TEXAS 2/4/87

TO: Bethlehem Steel Corporation | REPORT NO. 93280-cr

PROJECT Mechanical Testing of Welding Procedure | ORDER NO. 6939-001

MATERIAL A-710 Cl.3 Modified 3-1/4" TK

IDENTIFICATION #8

SPEC. REFERENCE ASME Sec. IX, SWL No. 9706-103-75 Rev. 1

Specimen	Size	Sq. In. Area	Yield, p.s.i.*	Ultimate Strength, lbs.	Tensile Strength, p.s.i.	% El.	% R.A.	Location of Fracture
REQUIRED:								
T-1	.733 x .705	.5167	103,735	60,500	117,089			Weld Metal
T-2	.734 x .659	.4837	106,676	54,500	112,671			Weld Metal
T-3	.510" Dia.	.2043	76,113	15,770	77,190	2.5%		

Side Bend #1 - UnSatisfactory
Side Bend #2 - UnSatisfactory
Side Bend #3 - Satisfactory
Side Bend #4 - Satisfactory

TECHNICIAN: John Blair

COPIES TO: 3-Jim Hyatt

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Figure A-23. Tensile and Bend Tests for Plate III-8

541-D

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FORT WORTH DALLAS HOUSTON MIDLAND BEAUMONT TEXARKANA

FILE NO. 4092300

Beaumont, TEXAS 2/4/87

IMPACT TESTS ON STEEL

To Bethlehem Steel Corporation

P. O. No. 6939-001 Date of Test 2/2/87

Material A-710, C13 Modified, 3-1/4" TK

Identification Marks #8

Specifications ASTM A-370, SWL No. 9706-102-75 Rev. 2

Testing Machine: T.O. Ser.# 88440 Test Method: "V" Notch Simple Beam Charpy
Linear Velocity of Hammer: 16.8 ft. per second
Effective Energy: 264 ft. pounds Specimen Type: "A"
Specimen Size: 10mm x 10mm Specimen Temp: Minus 60°F

Specimen Identification		Width, In Inches	Effective Section Size, In Inches	Impact Value Ft. Pounds	Lateral Exp. Mills	% Shear
Weld	#1	.394	.315	69.0	37.0	50
	2	.394	.315	33.0	12.0	30
	3	.394	.315	52.0	25.0	30
Fusion Line Plus 1mm	#1	.394	.315	141.0	64.0	80
	2	.394	.315	150.0	68.0	80
	3	.394	.315	56.0	25.0	60
Fusion Line Plus 5mm	#1	.394	.315	142.0	74.0	90
	2	.394	.315	122.0	60.0	90
	3	.394	.315	150.0	71.0	90

Copies:
3-Jim Hyatt

SOUTHWESTERN LABORATORIES

PER Jack D. Turner

Lab. No. 93318-cr

Figure A-24. Impact Tests at -60 Degrees F for Plate III-8

SwL **SOUTHWESTERN LABORATORIES**

Materials, environmental and geotechnical engineering, nondestructive, metallurgical and analytical services

222 Cavalcade St • P.O. Box 8768, Houston Texas 77249 • 713 692 9151

Attention: *SwL - Beaumont / Mr. John Blair*
Bethlehem Steel Corporation

Report No: 94644
File No:
Date: 10/07/88
SwL-Houston Report No: 881631

Project: Photomacrograph of One 3-1/4" S.A.W. Narrow Gap Weldment

PROJECT INFORMATION

Material:	One - 3-1/4" Thick S.A.W. Narrow Gap Weldment		
Identification:	SwL - Houston Report No. 881631		
Date Received:	October 07, 1988	*Technician:*	Wesley Bodenhamer
Specifications:	Per Client	*Date of Test:*	October 07, 1988
Test Equipment:	Standard Laboratory	*Procedure:*	ASTM E 3

TEST RESULTS

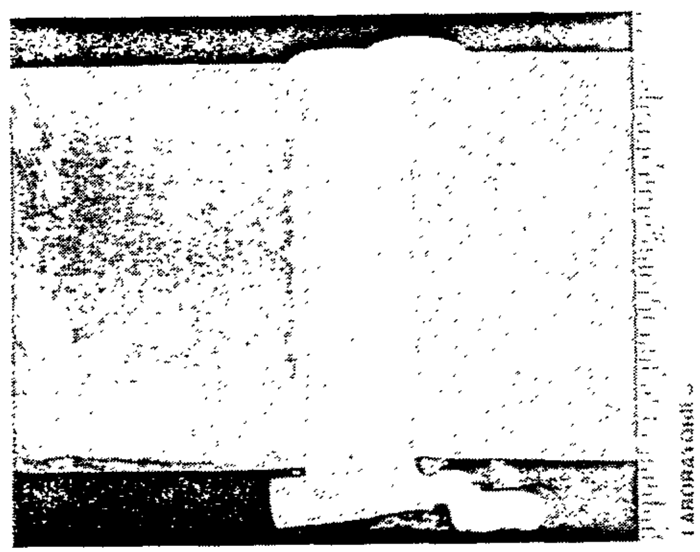

Figure 1 Mag: 0.89X Etch: 2% Nital

PHASE III TEST PLATE #8

Photomacrograph of a Cross Section on the 3-1/4" Test Plate

SOUTHWESTERN LABORATORIES

tda

Reviewed By

Figure A-25. Macro Photo of Plate III-8

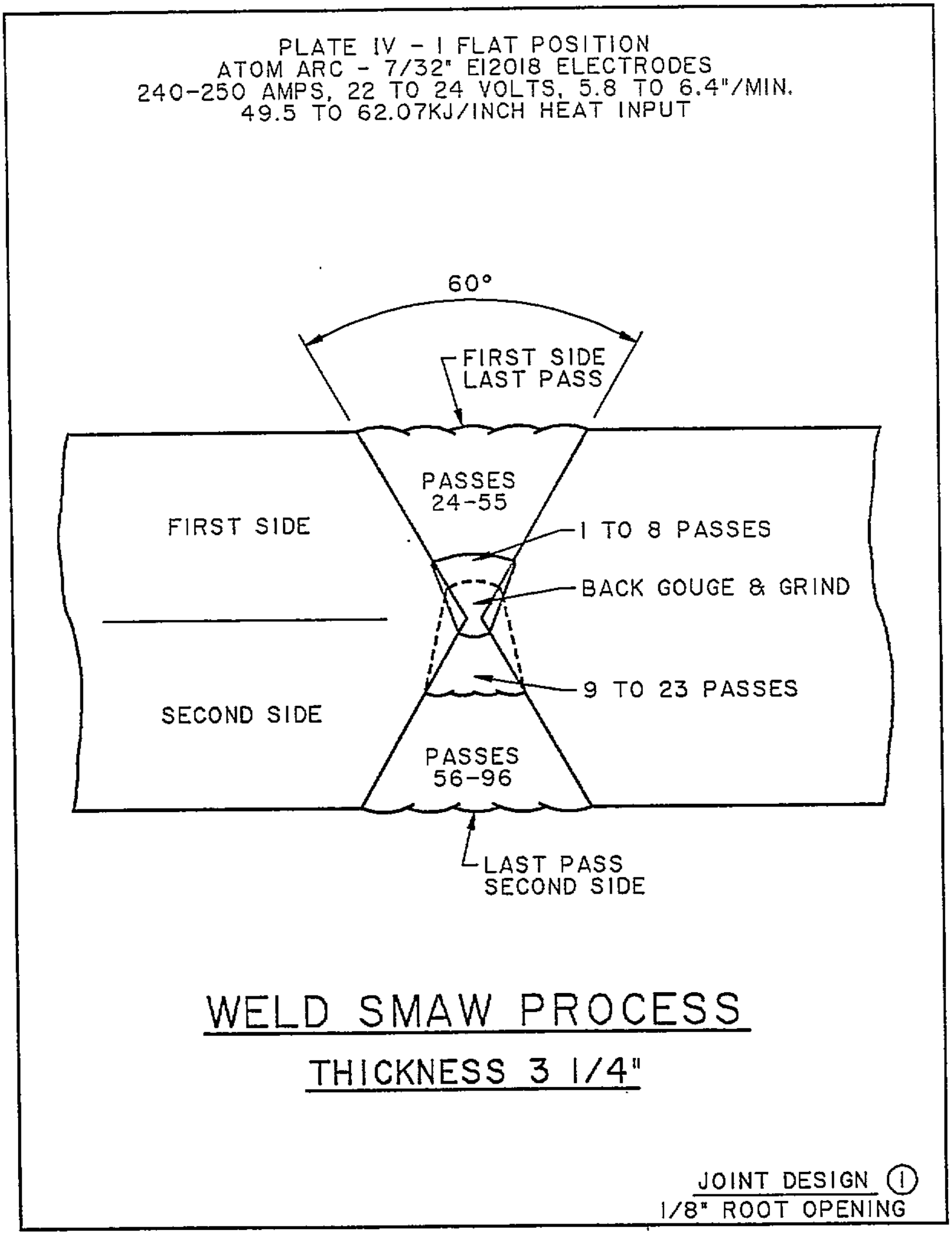

Figure A-26. SMAW Test Assembly for 3-1/4-Inch Thick
100 ksi Yield Strength Steel Plate

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REPORT OF TESTS ON METAL SPECIMENS

FILE NO. 4092300

Beaumont TEXAS 6/10/88

TO: Bethlehem Steel Corporation

REPORT NO. 94301-je

PROJECT Mechanical Testing of Welding Procedure

ORDER NO. S-8805-1012
Req. No. 0230-0008

MATERIAL A-710, Grade A, Class 3, 3-1/4" thick

IDENTIFICATION Process: SMAW

SPEC. REFERENCE ASME Sec. IX, SWL No. 9706-103-75 Rev. 1

Specimen	Size	Sq. In. Area	Yield, p.s.i.*	Ultimate Strength, lbs.	Tensile Strength, p.s.i.	% El.	% R.A.	Location of Fracture
REQUIRED:								
T-1	.748 x .973	.7628	108,018	91,600	120,078			Parent Metal
T-2	.749 x .944	.7070	108,902	82,700	116,963			Parent Metal
T-3 (All weld)	.508" dia.	.2027	129,255	28,100	138,628	20%	60%	

Side Bend #1 - Satisfactory

Side Bend #2 - Satisfactory

Side Bend #3 - Unsatisfactory

Side Bend #4 - Satisfactory

TECHNICIAN: John Blair

COPIES TO: 2-John West

SOUTHWESTERN LABORATORIES

Jack W. Durrell

PHASE IV - PLT 1

Figure A-27. Tensile and Bend Tests for Plate IV-1

241-D

SOUTHWESTERN LABORATORIES

FORT WORTH DALLAS HOUSTON MIDLAND BEAUMONT TEXARKANA

FILE NO. 4092300

Beaumont TEXAS 6/23/88

IMPACT TESTS ON STEEL

To Bethlehem Steel Corporation

P. O. No. S-8805-1012, Req. No. 0230-0008 Date of Test 6/10/88

Material A-710, Grade A, Class 3, 3-1/4" thick

Identification Marks Process: SMAW

Specifications ASTM A-370, SW1 No. 9706-102-75 Rev. 2

Testing Machine: T.O. Ser. # 88440 Test Method: "V" Notch Simple Charpy
Linear Velocity of Hammer: 16.8 ft. per second
Effective Energy: 264 ft. pounds Specimen Type: "A"
Specimen Size: 10mm x 10mm Specimen Temp: Minus 60° F.

Specimen Identification		Width, In Inches	Effective Section Size, In Inches	Impact Value Ft. Pounds	Lateral Exp. Mills	% Shear
Weld	#1	.394	.315	28	10	30
	#2	.394	.315	27	6	20
	#3	.394	.315	41	16	40
Fusion Line plus 1mm	#1	.394	.315	80	41	50
	#2	.394	.315	137	71	80
	#3	..394	.315	136	68	80
Fusion Line plus 5mm	#1	.394	.315	124	74	90
	#2	.394	.315	18.5	2	20
	#3	.394	.315	130	67	90

Copies: John West

SOUTHWESTERN LABORATORIES

PER Jack M. Sirnel

PHASE IV - PLATE 1

Lab. No. 94256-je

Figure A-28. Impact Tests for Plate IV-1

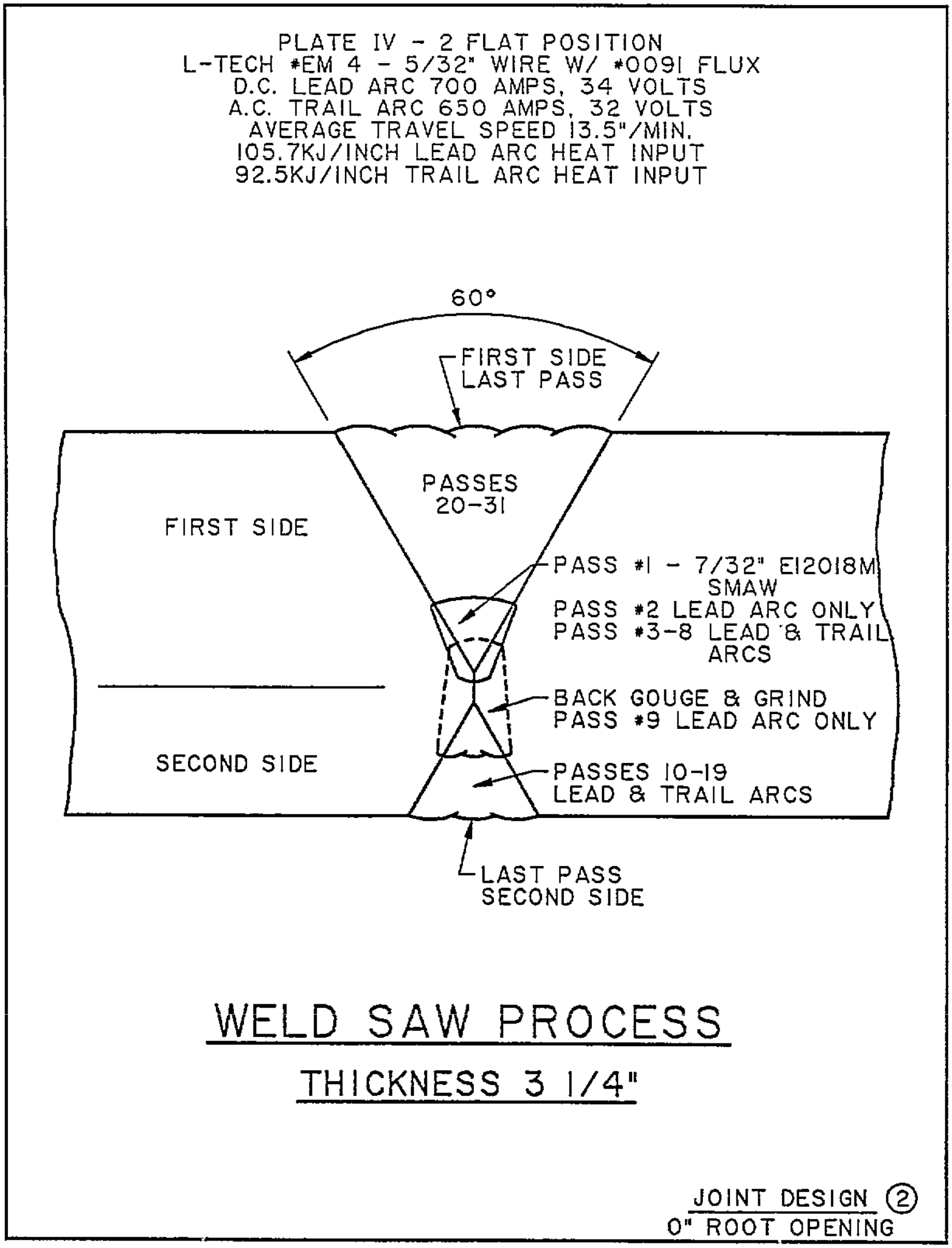

Figure A-29. Dual Sub Arc Weld Test Assembly
for 3-1/4-Inch Thick 100 ksi Yield Strength Steel Plate

SOUTHWESTERN LABORATORIES

REPORT OF TESTS ON METAL SPECIMENS

FILE NO. 4092300

Beaumont TEXAS 6/16/88

TO: Bethlehem Steel Corporation

REPORT NO. 94280-je

PROJECT Mechanical Testing of Welding Procedure

ORDER NO. S-8805-1012
Req. No. 0230-0008

MATERIAL A-710, Grade A, Class 3, 3-1/4" thick

IDENTIFICATION Process: SAW

SPEC. REFERENCE ASME Sec. IX, SWL NO. 9706-103-75 Rev. 1

Specimen	Size	Sq. In. Area	Yield, p.s.i.*	Ultimate Strength, lbs.	Tensile Strength, p.s.i.	% El.	% R.A.	Location of Fracture
REQUIRED:								
T-1	.755 x .931	.7029	93,611	77,700	110,541			Weld Metal
T-2	.754 x .976	.7359	105,176	86,400	117,406			Weld Metal
T-3 (All weld)	.501" dia.	.1971	81,177	21,280	107,965	24%	65%	

Side Bend #1 - Satisfactory

Side Bend #2 - Satisfactory

Side Bend #3 - Satisfactory

Side Bend #4 - Satisfactory

TECHNICIAN: John Blair

COPIES TO: 2-John West

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SOUTHWESTERN LABORATORIES

John B. Blair

PHASE IV - PLT 2

Figure A-30. Tensile and Bend Tests for Plate IV-2

241-D

SOUTHWESTERN LABORATORIES

FORT WORTH DALLAS HOUSTON MIDLAND BEAUMONT TEXARKANA

FILE No. 4092300

Beaumont TEXAS 6/23/88

IMPACT TESTS ON STEEL

To Bethlehem Steel Corporation

P. O. No. S-8805-1012, Req. No. 0230-008 Date of Test 6/21/88

Material A-710 Grade A, Class 3, 3-1/4" thick

Identification Marks Process: S.A.W.

Specifications ASTM A-370, SWL No. 9706-102-75 Rev. 2

Testing Machine: T.O. Ser. # 88440 Test Method: "V" Notch Simple Charpy
Linear Velocity of Hammer: 16.8 ft. per second
Effective Energy: 264 ft. pounds Specimen Type: "A"
Specimen Size: 10mm x 10mm Specimen Temp: Minus 60° F.

Specimen Identification		Width, In Inches	Effective Section Size, In Inches	Impact Value Ft. Pounds	Lateral Exp. Mills	% Shear
Weld	#1	.394	.314	15.5	2	20
	#2	.394	.315	16.0	3	20
	#3	.394	.315	25.0	8	20
Fusion Line plus 1mm	#1	.394	.315	26.5	10	20
	#2	.393	.315	39.0	17	20
	#3	.394	.315	19.5	8	20
Fusion Line plus 5mm	#1	.394	.315	158	71	70
	#2	.394	.315	151	65	80
	#3	.394	.315	164	60	80

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SOUTHWESTERN LABORATORIES
PER Jack W. Dunn[?]
PHASE IV - PLT 2

Lab. No. 99316-je

Figure A-31. Impact Tests for Plate IV-2 at -60 Degrees F

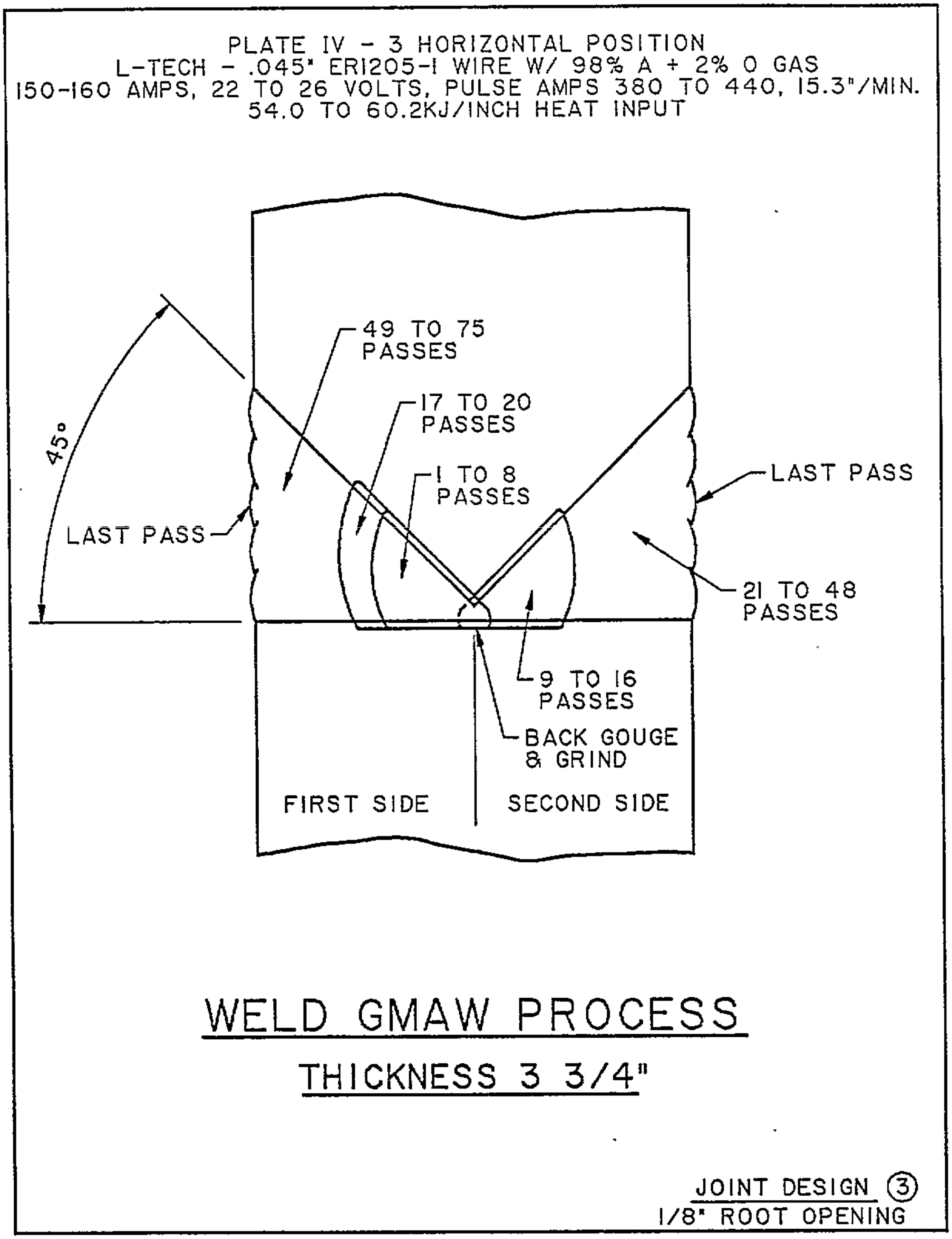

Figure A-32. Metal Arc Weld Test Assembly
for 3-3/4-Inch Thick 100 ksi Yield Strength Steel Plate

SOUTHWESTERN LABORATORIES

REPORT OF TESTS ON METAL SPECIMENS

FILE NO. 4092300

Beaumont TEXAS 5/9/88

TO: Bethlehem Steel Corporation

REPORT NO. 94221-je

PROJECT Mechanical Testing of Welding Procedure

ORDER NO. S-8805-1012

Req. # 0230-0008

MATERIAL A-710, Grade A, Class 3, ~~1"~~ 3 3/4" thick

IDENTIFICATION Process: GMAW Phase 4, Plate ~~#~~ 3

SPEC. REFERENCE ASTM A-370, sWI No. 9706-103-75 Rev. 1

Specimen	Size	Sq. In. Area	Yield, p.s.i.*	Ultimate Strength, lbs.	Tensile Strength, p.s.i.	% El.	% R.A.	Location of Fracture
REQUIRED:								
T-1	1.498 x 1.027	1.538	117,001	181,800	118,171			Weld Metal
T-2	1.502 x .996	1.495	120,187	185,800	124,198			Weld Metal
T-3 (All weld)	.508" dia.	.2027	132,708	28,100	138,628	19%	63%	

Side Bend #1 - Unsatisfactory

Side Bend #2 - Unsatisfactory

Side Bend #3 - Unsatisfactory

Side Bend #4 - Unsatisfactory

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TECHNICIAN: John Blair

COPIES TO: 2-John West

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John B. Blair

PHASE IV - PLT 3

Figure A-33. Tensile and Bend Tests for Plate IV-3

241-D

SOUTHWESTERN LABORATORIES

FORT WORTH DALLAS HOUSTON MIDLAND BEAUMONT TEXARKANA

FILE No. 4092300

Beaumont, TEXAS 5/11/88

IMPACT TESTS ON STEEL

To Bethlehem Steel Corporation

P. O. No. S-8805-1012, Req.# 0230-0008 Date of Test 5/9/88

Material A-710 Grade A Class 3, 3 3/4" thick

Identification Marks Process: GMAW Phase 4, Plate #3

Specifications ASTM A-370, SW1 No. 9706-102-75 Rev. 2

Testing Machine: T.O. Ser. # 88440 Test Method: "V" Notch Simple Charpy
Linear Velocity of Hammer: 16.8 ft. per second
Effective Energy: 264 ft. pounds Specimen Type: "A"
Specimen Size: 10mm x 10mm Specimen Temp: Minus 60° F.

Specimen Identification		Width, In Inches	Effective Section Size, In Inches	Impact Value Ft. Pounds	Lateral Exp. Mills	% Shear
Weld	#1	.393	.315	53	29	70
	#2	.394	.315	60	24	60
	#3	.394	.315	53	25	60
Fusion Line + 1mm	#1	.393	.315	147	76	80
	#2	.394	.315	136	71	80
	#3	.393	.315	140	72	80
Fusion Line + 5mm	#1	.394	.315	106	52	80
	#2	.394	.315	112	57	80
	#3	.394	.315	140	73	80

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ENGINEERING DEPT.

SOUTHWESTERN LABORATORIES

Per John B. Blair
Phase IV - Plt 3

Lab. No. 94232-3e

Figure A-34. Impact Tests for Plate IV-3 at -60 Degrees F

Figure A-35. INTENTIONALLY LEFT BLANK

SwL

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Attention:
Bethlehem Steel

SEP 13 88

Report No: 94561
File No: 4092300
Date: 09/12/88
P.O. No:
Houston Report No.: 881442

Project: Photographs of One 3 1/4" Weldment

PROJECT INFORMATION

Material:	One - Section of an A 710 Class 3 Grade A Modified 3 3/4" Thick G.M.A.W. Process Test Plate 8 3/8" Wide x 1/2" Long		
Identification:	SwL Houston Met Lab No. 881442		
Date Received:	September 07, 1988	*Technician:*	Stan Daigle
Specifications:	Per Client	*Date of Test:*	September 09, 1988
Test Equipment:	Metallographic	*Procedure:*	ASTM E 3

TEST RESULTS

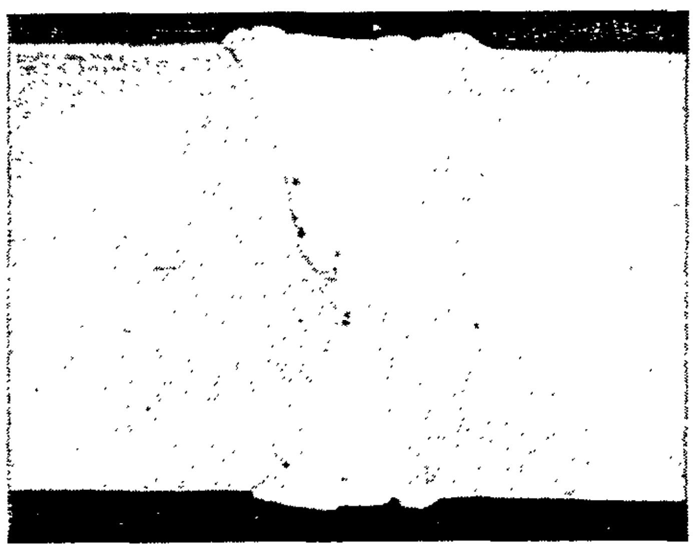

Figure 1 Mag: 0.9X Etch: 2% Nital

Photomacrograph of a cross section of the weldment.

PHASE IV TEST PLATE #3

Figure A-36. Macro Photo of Plate IV-3

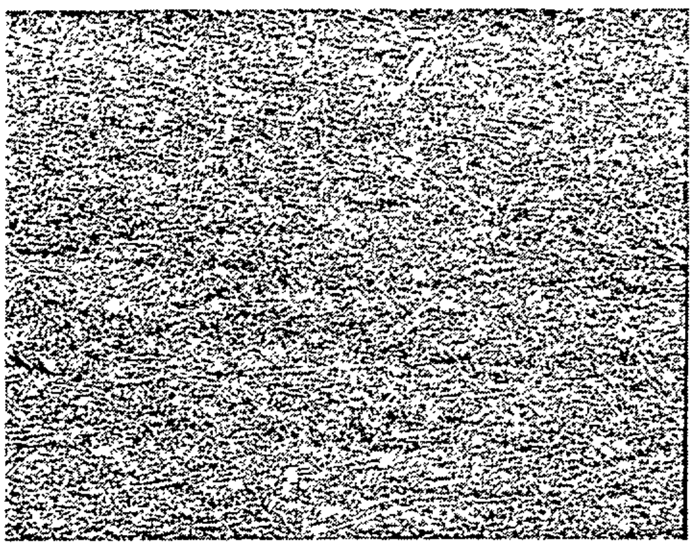

Figure No. 2 Mag: 500X Etch: 2% Nital
PHASE IV TEST PLATE #3

Photomicrograph of the weld metal consisting of Widmanstatten ferrite platelets and a small percentage of pearlite; typical of low carbon steel weld metal. Photomicrograph was taken at approximately 1" from the surface of the plate.

SOUTHWESTERN LABORATORIES

Reviewed By

ckl

Figure A-37. Microstructure of Plate IV-3

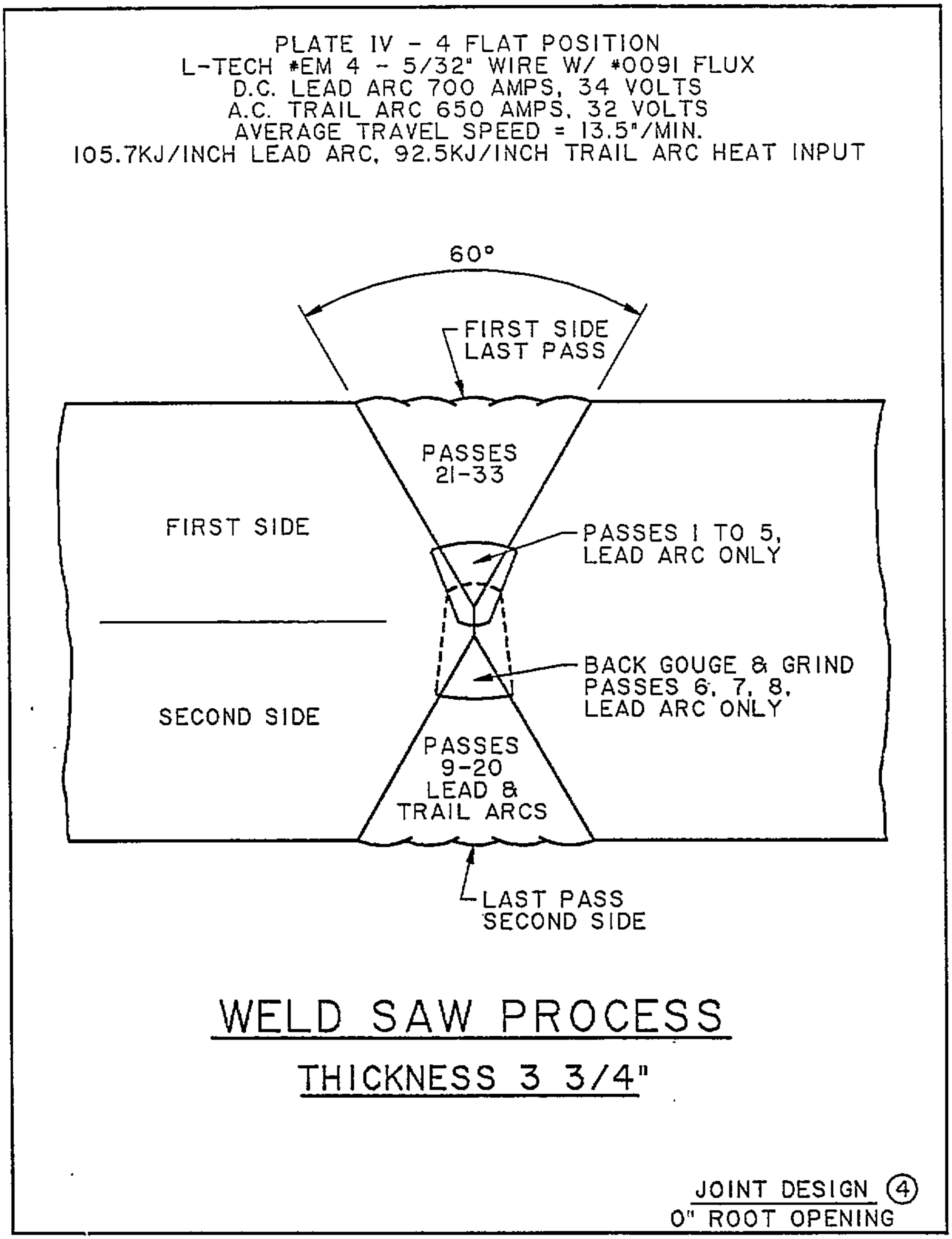

Figure A-38. Dual Sub Arc Weld of 3-3/4-Inch Thick
100 ksi Yield Strength Steel Plate

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REPORT OF TESTS ON METAL SPECIMENS

FILE NO. 4092300

Beaumont TEXAS 5/20/88

'O: Bethlehem Steel Corporation

REPORT NO. 94251-je

'ROJECT Mechanical Testing of Procedure Qualifications

ORDER NO.

IATERIAL A-710, Grade A, Class 3, 3-3/4" thick

DENTIFICATION Process: SAW

iPEC. REFERENCE ASME Sec. IX, SWL No. 9706-103-75 Rev. 1

ecimen	Size	Sq. In. Area	Yield, p.s.i.*	Ultimate Strength, lbs.	Tensile Strength, p.s.i.	% El.	% R.A.	Location of Fracture
QUIRED:								
-1	.745 x .957	.7129	101,688	77,600	108,841			Weld Metal
-2	.741 x .982	.7276	109,941	82,200	112,964			Weld Metal
-3 .1 weld)	.507" dia.	.2019	90,391	21,830	108,122	25%	58%	

ide Bend #1 - Satisfactory

ide Bend #2 - Satisfactory

ide Bend #3 - Satisfactory

ide Bend #4 - Satisfactory

CHNICIAN: John Blair

PIES TO: 2-Bethlehem Steel

SOUTHWESTERN LABORATORIES

Jack B. Turner

Figure A-39. Tensile and Bend Tests for Plate IV-4

241-D

SOUTHWESTERN LABORATORIES

FORT WORTH DALLAS HOUSTON MIDLAND BEAUMONT TEXARKANA

FILE No. 4092300

Beaumont, TEXAS, 5/23/88

IMPACT TESTS ON STEEL

To: Bethlehem Steel Corporation

P. O. No. ______ Date of Test: 5/20/88

Material: A-710, Grade A, Class 3, 3-3/4" thick

Identification Marks: Process: SAW

Specifications: ASTM A-370, SWL No. 9706-102-75 Rev. 2

Testing Machine: T.O. Ser. # 88440 Test Method: "V" Notch Simple Beam Charpy

Linear Velocity of Hammer: 16.8 ft. per second

Effective Energy: 264 ft. pounds Specimen Type: "A"

Specimen Size: 10mm x 10mm Specimen Temp: Minus 60° F.

Specimen Identification		Width, In Inches	Effective Section Size, In Inches	Impact Value Ft. Pounds	Lateral Exp. Mills	% Shear
Weld	#1	.394	.315	19.5	5	20
	#2	.394	.315	24.0	8	20
	#3	.394	.315	16.0	4	20
Fusion Line plus 1mm	#1	.394	.315	145	65	80
	#2	.394	.315	172	69	80
	#3	.394	.315	157	75	80
Fusion Line plus 5mm	#1	.394	.315	107	55	90
	#2	.394	.315	106	53	90
	#3	.394	.315	108	54	90

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PER Jack D. Summers

Lab. No. 94242-je

Figure A-40. Impact Tests for Plate IV-4 at -60 Degrees F

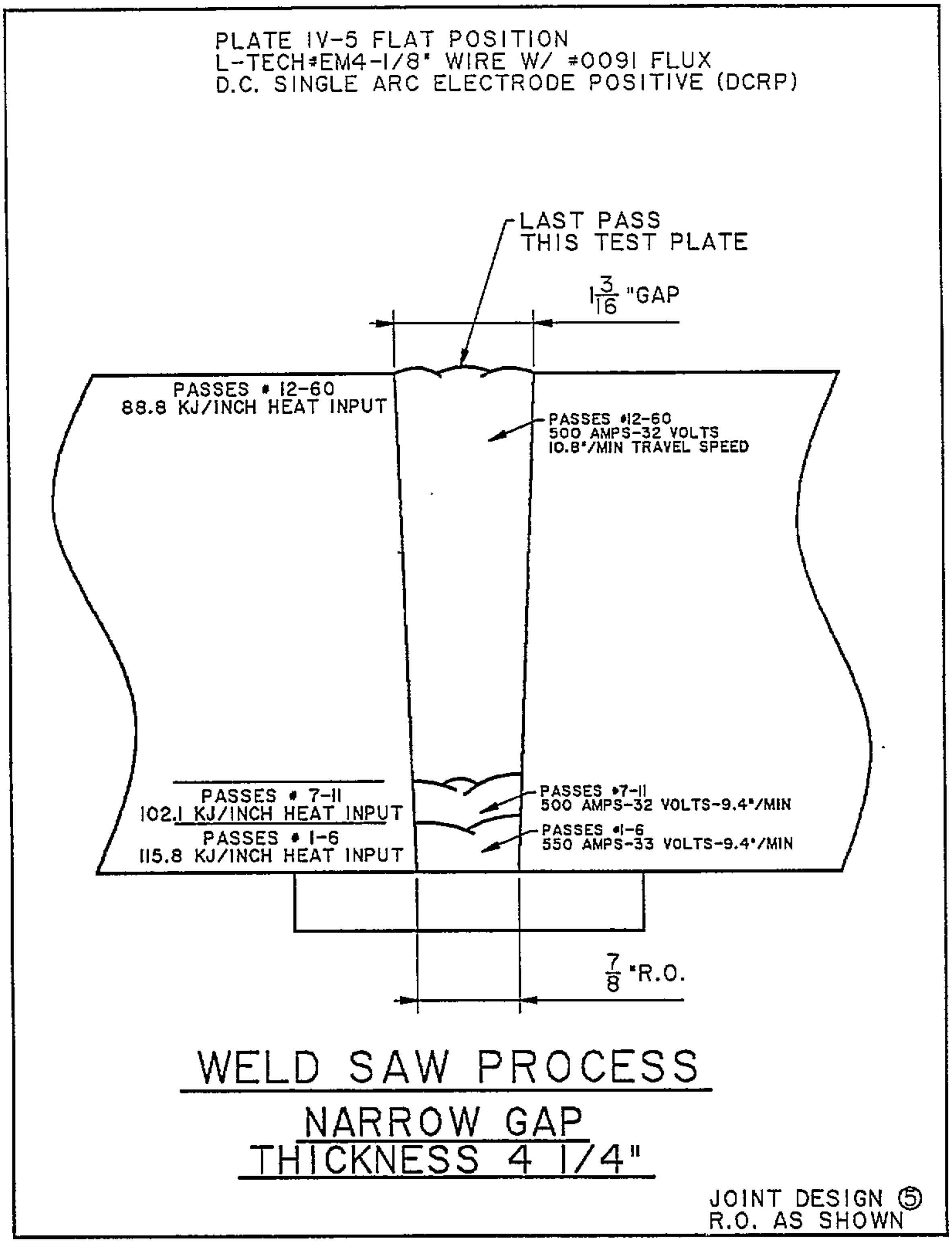

Figure A-41. Narrow Gap Sub Arc Weld Test Assembly for 4-1/4-Inch Thick 100 ksi Yield Strength Steel Plate

SOUTHWESTERN LABORATORIES

REPORT OF TESTS ON METAL SPECIMENS

FILE NO. 4092300

Beaumont TEXAS 9/1/88

TO: Bethlehem Steel Corporation

REPORT NO. 94544-je

PROJECT Mechanical Testing of Welding Procedure

ORDER NO.

MATERIAL A-710, Class 3, Grade A Modified, 4-1/4" thick

IDENTIFICATION SAW Narrow Gap

SPEC. REFERENCE ASME Sec. IX, SWL No. 9706-103-75 Rev. 1

Specimen	Size	Sq. In. Area	Yield, p.s.i.*	Ultimate Strength, lbs.	Tensile Strength, p.s.i.	% El.	% R.A.	Location of Fracture
REQUIRED:								
T-1	.754 x .978	.7374	99,537	83,700	113,505			Weld Metal
T-2	.751 x 1.025	.7697	103,926	87,900	114,189			Weld Metal
T-3 (All weld)	.502" dia.	.1979	102,324	21,970	111,015	25.5%	64%	

Side Bend #1 - Unsatisfactory

Side Bend #2 - Satisfactory

Side Bend #3 - Satisfactory

Side Bend #4 - Satisfactory

TECHNICIAN: John Blair

COPIES TO: John West

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John B. Blair

PHASE IV - PLT 5

Figure A-42. Tensile and Bend Tests for Plate IV-5

241-D

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FORT WORTH DALLAS HOUSTON MIDLAND BEAUMONT TEXARKANA

FILE No. 4092300

Beaumont, TEXAS, 9/7/88

IMPACT TESTS ON STEEL

To: Bethlehem Steel Corporation

P. O. No. ______ Date of Test: 9/1/88

Material: A-710, Class 3, Grade A, 4-1/4" thick

Identification Marks: SAW Narrow Gap

Specifications: ASTM A-370, SWI No. 9706-102-75 Rev. 2

Testing Machine: T.O. Ser. # 88440 Test Method: "V" Notch Simple Charpy
Linear Velocity of Hammer: 16.8 ft. per second
Effective Energy: 264 ft. pounds Specimen Type: "A"
Specimen Size: 10mm x 10mm Specimen Temp: Minus 60° F.

Specimen Identification		Width, In Inches	Effective Section Size, In Inches	Impact Value Ft. Pounds	Lateral Exp. Mills	% Shear
Weld	#1	.394	.315	10.5	7	20
	#2	.394	.315	14.0	11	20
	#3	.393	.315	13.0	7	20
Fusion Line +1mm	#1	.394	.315	202.0	87	90
	#2	.394	.315	190.0	86	90
	#3	.394	.315	201.0	92	90
Fusion Line + 5mm	#1	.394	.315	140.0	82	90
	#2	.394	.315	182.0	90	90
	#3	.394	.315	143.0	76	90

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PER John B. Blair
PHASE IV - PLT 5

Lab. No. 94576-je

Figure A-43. Impact Tests for Plate IV-5 at -60 Degrees F

241-D

SOUTHWESTERN LABORATORIES

FORT WORTH DALLAS HOUSTON MIDLAND BEAUMONT TEXARKANA

FILE NO. 4092300

Beaumont TEXAS 9/7/88

IMPACT TESTS ON STEEL

To Bethlehem Steel Corporation

P. O. No. ____ Date of Test 9/1/88

Material A-710, Class 3, Grade A, 4-1/4" thick

Identification Marks SAW Narrow Gap

Specifications ASTM A-370, SW1 No. 9706-102-75 Rev. 2

Testing Machine: T.O. Ser. # 88440 Test Method: "V" Notch Simple Charpy
Linear Velocity of Hammer: 16.8 ft. per second
Effective Energy: 264 ft. pounds Specimen Type: "A"
Specimen Size: 10mm x 10mm Specimen Temp: Minus 20° F.

Specimen Identification	Width, In Inches	Effective Section Size, In Inches	Impact Value Ft. Pounds	Lateral Exp. Mills	% Shear
Weld #1	.393	.315	26.0	18	20
#2	.394	.315	23.0	17	20
#3	.394	.315	35.0	20	20

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PER John B. Blair

PHASE IV - PLT 5

Lab. No. 94577-je

Figure A-44. Impact Tests for Plate IV-5 at -20 Degrees F

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Attention:
Bethlehem Steel

Report No: 94544
File No:
Date: 09/07/88
P.O. No:
Houston Report No.: 881398

Project: Photographs of One 4 1/4" S.A.W. Narrow Gap Weldment

PROJECT INFORMATION

Material:	One - 12" x 6" x 4 1/4" Thick S.A.W. Narrow Gap Weldment		
Identification:	SwL Houston Met Lab No. 881398		
Date Received:	August 30, 1988	*Technician:*	Stan Daigle
Specifications:	Per Client	*Date of Test:*	September 06, 1988
Test Equipment:	Metallographic	*Procedure:*	ASTM E 3

TEST RESULTS

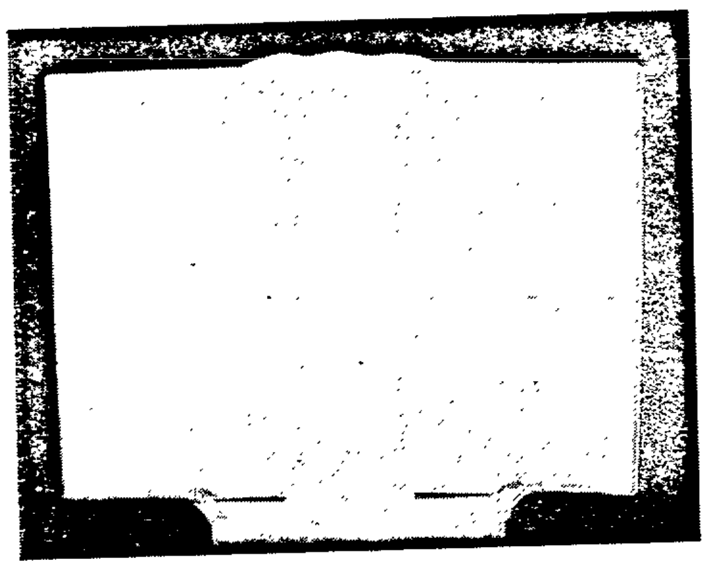

Figure 1 Mag: 0.66 Etch: 2% Nital
PHASE IV TEST PLATE #5

Photomicrograph of a cross section of the S.A.W. narrow gap weldment.

Figure A-45. Macro Photo of 4-1/4-Inch Narrow Gap Sub Arc Weld

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Attention:
Bethlehem Steel

Report No: 94544ADD
File No:
Date: 09/07/88
P.O. No:
Houston Report No.: 881398
ADDITION to report completed 09/07/88

Project: Photographs of One 4 1/4" S.A.W. Narrow Gap Weldment

PROJECT INFORMATION

Material:	One - 12" x 6" x 4 1/4" Thick S.A.W. Narrow Gap Weldment		
Identification:	SwL Houston Met Lab No. 881398		
Date Received:	August 30, 1988	*Technician:*	Stan Daigle
Specifications:	Per Client	*Date of Test:*	September 1406, 1988
Test Equipment:	Metallographic	*Procedure:*	ASTM E 3

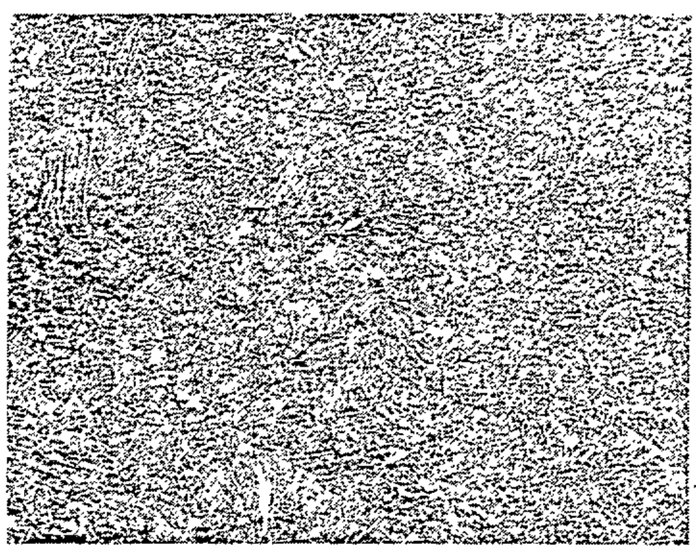

Figure 31 Mag: 320X Etch: 2% Nital
PHASE IV TEST PLATE #5
Microstructure at the fusion line with the photo primarily showing the HAZ which consisted of fine grained martensite.

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Dennis Stanfield
Reviewed By

Stan Daigle

ckl

Figure A-46. Microstructure of Plate IV-5 HAZ

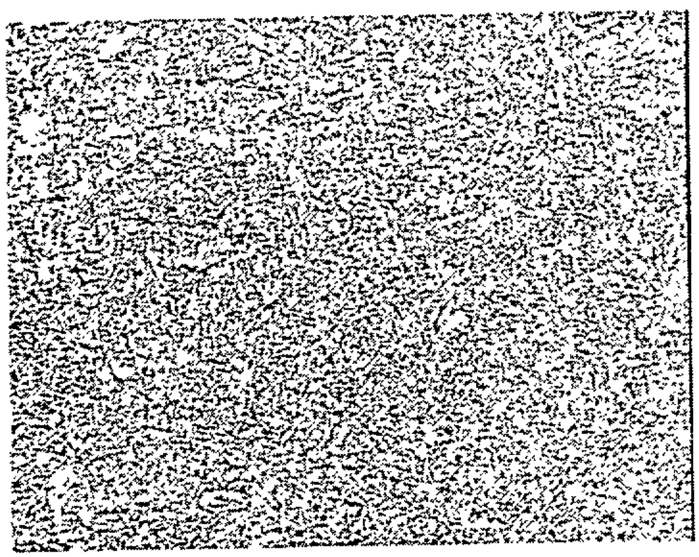

Figure No. 2 Mag: 500X Etch: 2% Nital

PHASE IV TEST PLATE #5

Photomicrograph of the weld metal consisting of fine grained ferrite and pearlite. Micro was taken at approximately 1" below the surface of the plate.

SOUTHWESTERN LABORATORIES

Dennis Stanfield
Reviewed By

ckl

Figure A-47. Microstructure of 4-1/4-Inch Thick Narrow Gap Sub Arc Weldmetal - Plate IV-5

SwL **SOUTHWESTERN LABORATORIES**

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Attention:
Bethlehem Steel
Attn: John West

Report No: 94625
File No: 2285846
Date: 09/27/88
P.O. No: 0230-0008
Houston Report No.: 22732

Project: Chemical Analysis of Steel Alloy

PROJECT INFORMATION

Material:	One - 4 1/4" Thick Welded Plate, Narrow Gap		
Identification:	As Per 21-09-94625		
Date Received:	September 23, 1988	*Technician:*	Bob Yount and Del Armstrong
Specifications:	N/A	*Date of Test:*	Sept. 23 to Sept. 27, 1988
Test Equipment:	Siemens SRS-200 XRF Leco IR-12 Carbon	*Procedure:*	ASTM E 322, ASTM E 1019

CHEMICAL COMPOSITION (WT. %)

Specimen Identification	C	Mn	Si	Ni	Cr	Mo	Cu
21-09-94625	0.073	1.01	0.59	2.16	0.27	0.47	0.18

PHASE IV TEST PLATE #5

SOUTHWESTERN LABORATORIES

ckl

Reviewed By

Figure A-48. Chemical Analysis of Plate IV-5

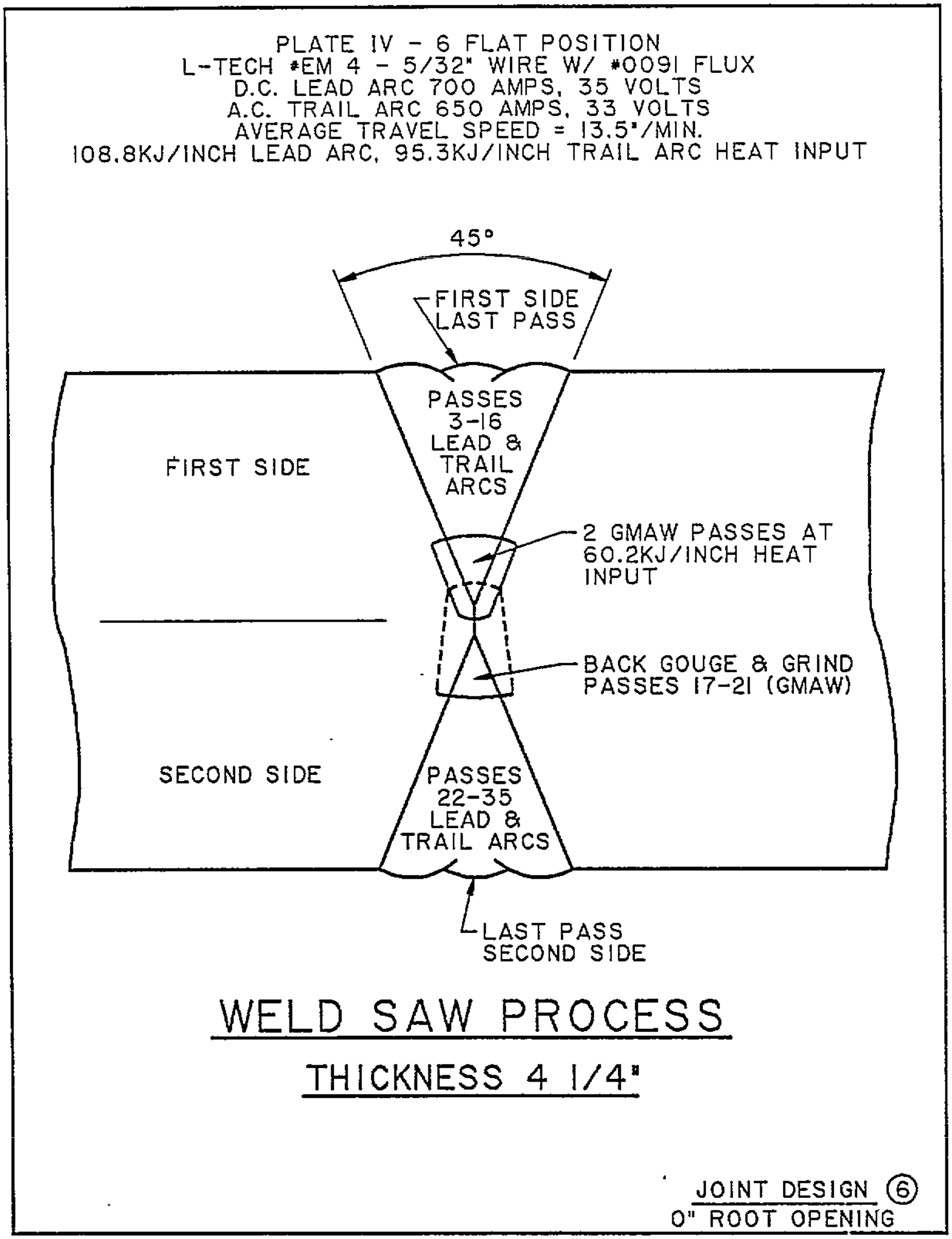

Figure A-49. Sub Arc Weld Test Assembly for 4-1/4-Inch Thick 100 ksi Yield Strength Steel - Plate IV-6

SOUTHWESTERN LABORATORIES

REPORT OF TESTS ON METAL SPECIMENS

FILE NO. 4092300

Beaumont TEXAS 6/9/88

TO: Bethlehem Steel Corporation

REPORT NO. 94300-je

PROJECT Mechanical Testing of Welding Procedure

ORDER NO. S-8805-1012
Req. No. 0230-0008

MATERIAL A-710 Grade A, Class 3, 4-1/4" thick

IDENTIFICATION Process: SAW

SPEC. REFERENCE ASME Sec. IX, SWL No. 9706-103-75 Rev. 1

Specimen	Size	Sq. In. Area	Yield, p.s.i.*	Ultimate Strength, lbs.	Tensile Strength, p.s.i.	% El.	% R.A.	Location of Fracture
REQUIRED:								
T-1	.747 x .962	.7186	104,089	82,100	114,247			Weld Metal
T-2	.755 x .934	.7051	92,459	79,200	112,313			Weld Metal
T-3 (all weld)	.506" dia.	.2011	87,518	21,730	108,055	23.5%	65.5%	

Side Bend #1 - Satisfactory

Side Bend #2 - Satisfactory

Side Bend #3 - Satisfactory

Side Bend #4 - Satisfactory

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TECHNICIAN: John Blair

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Jack D. Turner

PHASE IV - PLT 6

Figure A-50. Tensile and Bend Tests for Plate IV-6

241-D

SOUTHWESTERN LABORATORIES

FORT WORTH DALLAS HOUSTON MIDLAND BEAUMONT TEXARKANA

FILE No. 4092300

Beaumont TEXAS, 6/23/88

IMPACT TESTS ON STEEL

To: Bethlehem Steel Corporation

P. O. No. S-8805-1012, Req. No. 0230-0008 Date of Test 6/10/88

Material A-710, Grade A, Class 3, 4-1/4" thick

Identification Marks Process: SAW

Specifications ASTM A-370, SWL No. 9706-102-75 Rev. 2

Testing Machine: T.O. Ser. # 88440 Test Method: "V" Notch Simple Charpy
Linear Velocity of Hammer: 16.8 ft. per second
Effective Energy: 264 ft. pounds Specimen Type: "A"
Specimen Size: 10mm x 10mm Specimen Temp: Minus 60° F.

Specimen Identification		Width, In Inches	Effective Section Size, In Inches	Impact Value Ft. Pounds	Lateral Exp. Mills	% Shear
Weld	#1	.394	.315	9.0	0	10
	#2	.394	.315	11.0	2	10
	#3	.394	.315	13.5	3	20
Fusion Line plus 1mm	#1	.394	.315	15.5	10	20
	#2	.394	.315	163.0	67	90
	#3	.394	.315	37.0	20	30
Fusion Line plus 5mm	#1	.394	.315	106.0	57	80
	#2	.394	.315	19.0	6	20
	#3	.394	.315	14.5	12	20

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PER Jack D. Tirrell

PHASE IV - PL 6

Lab. No. 94273-je

Figure A-51. Impact Tests for Plate IV-6 at -60 Degrees F

241-D

SOUTHWESTERN LABORATORIES

FORT WORTH DALLAS HOUSTON MIDLAND BEAUMONT TEXARKANA

FILE NO. 4092300

Beaumont, TEXAS 8/19/88

IMPACT TESTS ON STEEL

To Bethlehem Steel Corporation

P. O. No. S-8805-1012 Date of Test 8/16/88

Material A-710 Class 3, Grade A Modified, 4-1/4" thick

Identification Marks SAW

Specifications ASTM A-370, SWL No. 9706-102-75 Rev. 2

Testing Machine: T.O. Ser. # 88440 Test Method: "V" Notch Simple Charpy

Linear Velocity of Hammer: 16.8 ft. per second

Effective Energy: 264 ft. pounds Specimen Type: "A"

Specimen Size: 10mm x 10mm Specimen Temp: Minus 40° F.

Specimen Identification	Width, In Inches	Effective Section Size, In Inches	Impact Value Ft. Pounds	Lateral Exp. Mills	% Shear
Weld #1	.394	.315	23.0	18	30
#2.	.394	.315	16.0	10	20
#3	.394	.315	23.0	18	30

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Reference: 94273

Copies: John West

SOUTHWESTERN LABORATORIES

PER John B. Blair

PHASE IV-PLT 6

Lab. No. 99495-je

Figure A-52. Impact Tests for Plate IV-6 at -40 Degrees F

PHOTOMACROGRAPH OF PHASE IV

TEST PLATE NO. 6

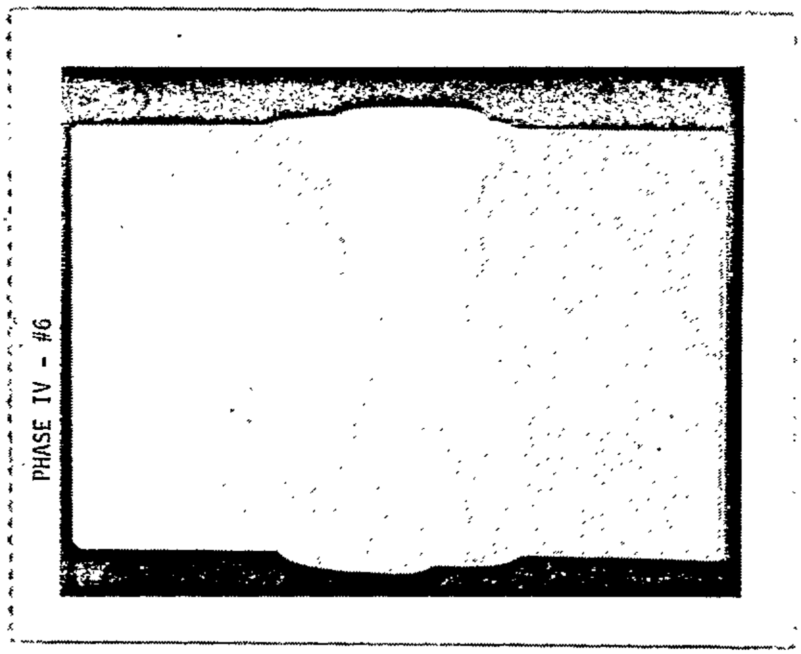

Figure A-53. Macro Photo of Plate IV-6

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BETHLEHEM STEEL CORPORATION

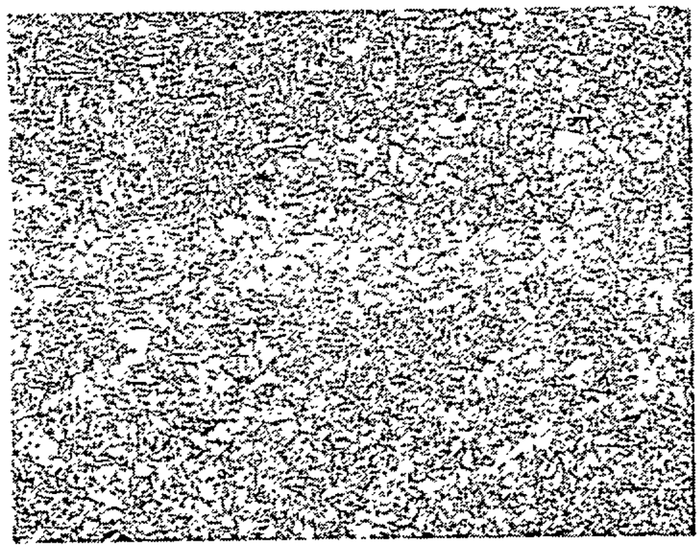

Figure No. 5 2% Nital

Microstructure at 500X in the weld metal on Sample No. 3.

PHASE IV TEST PLATE #6

Figure A-54. Microstructure of Plate IV-6 in Weld Metal

SOUTHWESTERN LABORATORIES
BETHLEHEM STEEL CORPORATION

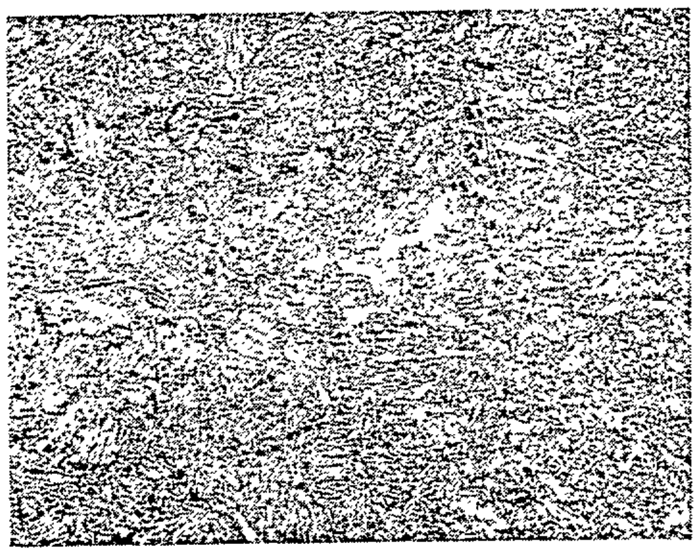

Figure No. 6 2% Nital

Microstructure at 320X near the fusion zone with the photo showing primarily HAZ on Sample No. 3.

PHASE IV TEST PLATE #6

Figure A-55. Microstructure of Plate IV-6 Near Heat Affected Zone

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Materials, environmental and geotechnical engineering, nondestructive, metallurgical and analytical services

222 Cavalcade St • PO Box 8768, Houston, Texas 77249 • 713-692-9151

Report No.: 94573
File No.:
Date: 09/06/88
Houston Report No.: 881411

Bethlehem Steel Corporation

Project: Photographs on Three ASTM A 710, Grade 3 Weld Plates

MATERIAL

Three - ASTM A 710, Grade 3 weld plates labeled Number 1, 2 and 3.

BACKGROUND

This laboratory received the above mentioned weld plates on September 01, 1988, along with a request to take photographs at 500X magnification in the weld metal and at the fusion zone, approximately one inch below the weld cap.

TEST RESULTS

The microstructure of the three samples at corresponding locations was essentially similar. The unaffected base metal consisted of a martensitic matrix with fine spheroidal precipitates. The heat affected zones also exhibited a martensitic matrix, but with a slightly greater degree of the precipitated phase. Samples #2 and #3 exhibited a greater degree of precipitation particularly at the grain boundaries, as illustrated in Figures No. 4 and No. 6 respectively. The fusion zone in all samples consisted of fine, dendritic ferrite with intermittent precipitates.

Respectfully,

SOUTHWESTERN LABORATORIES, INC.

York Patterson
Metallurgical Engineering Division

Reviewed By

YP:ckl

HOUSTON • DALLAS • AUSTIN • BEAUMONT • CONROE • GALVESTON COUNTY • RIO GRANDE VALLEY • ALEXANDRIA
SAN ANTONIO • FORT WORTH • LEESVILLE • MIDLAND • MONROE • SHREVEPORT • TEXARKANA • SHERMAN

Figure A-56. Metallurgy Laboratory Characterization of Plate IV-6, IV-8 and IV-10

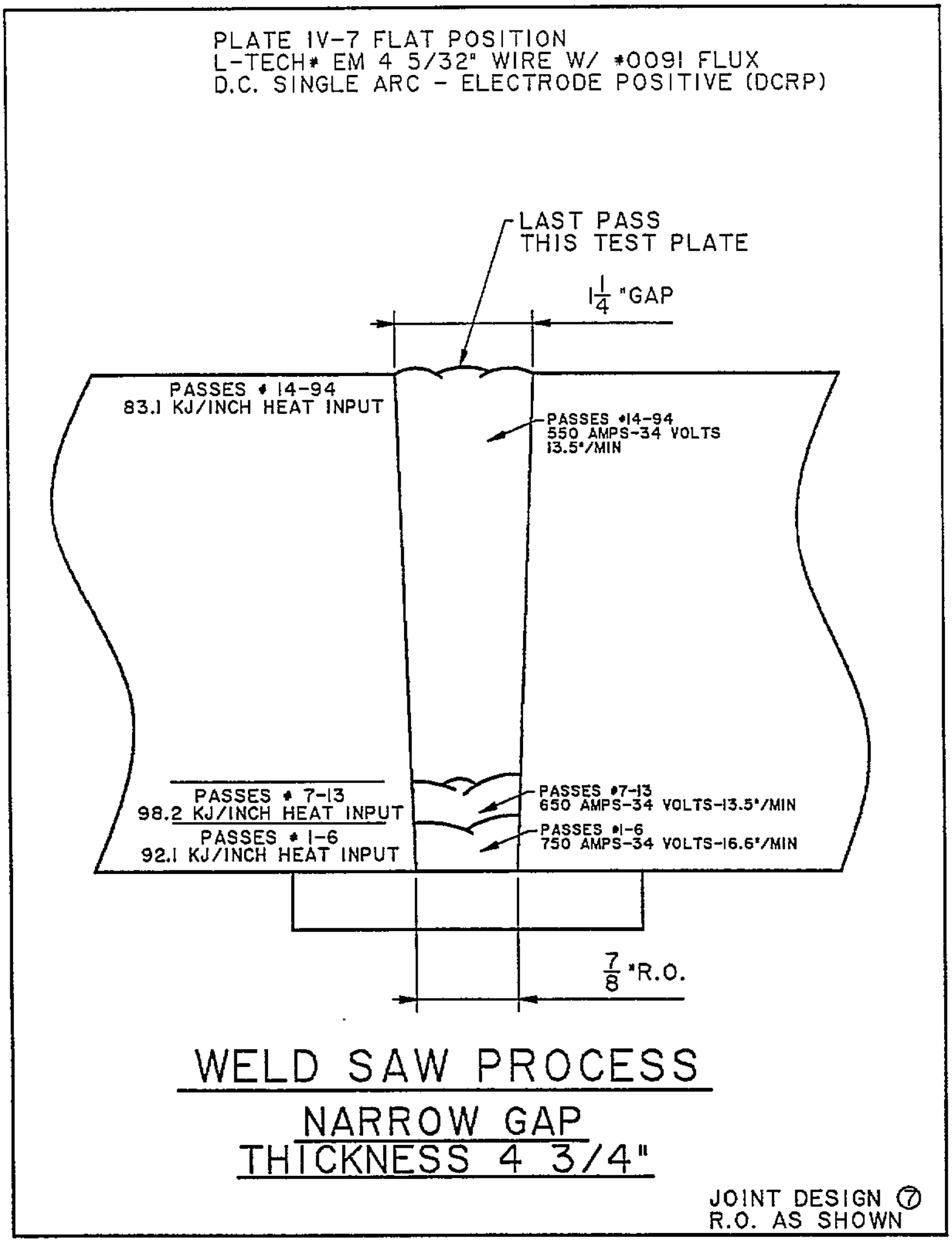

Figure A-57. Narrrow Gap Sub Arc Test Assembly for 4-3/4-Inch Thick 100 ksi Yield Strength Steel Plate

SOUTHWESTERN LABORATORIES

REPORT OF TESTS ON METAL SPECIMENS

FILE NO. 4092300

Beaumont TEXAS 8/26/88

TO: Bethlehem Steel Corporation

REPORT NO. 94540-je

PROJECT Mechanical Testing of Weld Procedure

ORDER NO. S-8805-1012
Req. No. 0230-0008

MATERIAL A-710 Class 3, Grade A, 4-3/4" thick

IDENTIFICATION S.A.W. Narrow Gap

SPEC. REFERENCE ASME Sec. IX, SWL No. 9706-103-75 Rev. 1

Specimen	Size	Sq. In. Area	Yield, p.s.i.*	Ultimate Strength, lbs.	Tensile Strength, p.s.i.	% El.	% R.A.	Location of Fracture
REQUIRED:								
T-1	.752 x 1.010	.7595	103,357	90,800	119,549			Weld Metal
T-2	.747 x 1.009	.7537	108,793	88,700	117,682			Parent Metal
T-3 (All weld)	.507" dia.	.2019	105,250	22,810	112,976	23%	64%	

Side Bend #1 - Unsatisfactory

Side Bend #2 - Satisfactory

Side Bend #3 - Satisfactory

Side Bend #4 - Satisfactory

TECHNICIAN: John Blair

COPIES TO: 2-John West

SOUTHWESTERN LABORATORIES

John B. Blair

PHASE IV - PLT 7.

Figure A-58. Tensile and Bend Tests for Plate IV-7

SwL SOUTHWESTERN LABORATORIES

Materials, environmental and geotechnical engineering, nondestructive, metallurgical and analytical services

222 Cavalcade St • PO Box 8768, Houston, Texas 77249 • 713 692-9151

Attention:
Bethlehem Steel Corporation

Report No: 94583
File No:
Date: 09/21/88
P.O. No:
Houston Report No.: 881474

Project: Photographs of One 4 3/4" Weldment and One 5 1/4" Weldment

PROJECT INFORMATION

Material:	One - 4 3/4" Wide S.A.W. Narrow Gap Test Plate; One - 5 1/4" Wide S.A.W. Narrow Gap Test Plate		
Identification:	Houston Report No. 881474		
Date Received:	September 13, 1988	*Technician:*	York Patterson
Specifications:	Per Client	*Date of Test:*	September 21, 1988
Test Equipment:	Metallographic	*Procedure:*	ASTM E 3

TEST RESULTS

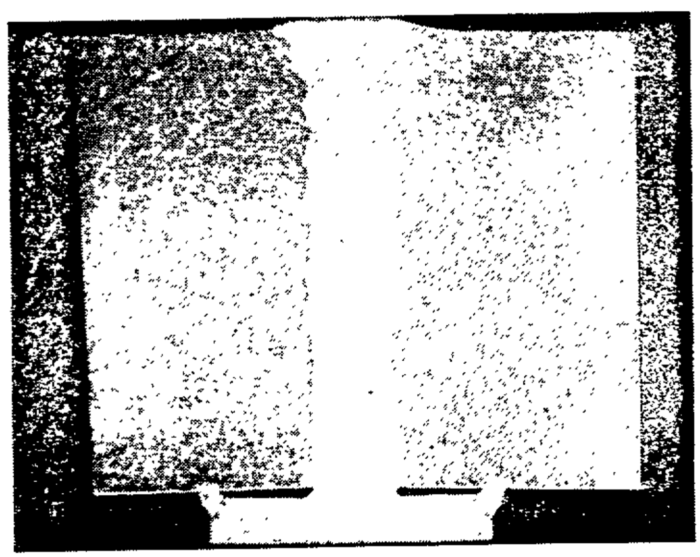

Figure 1 Mag: 0.6X Etch: 2% Nital
Photomacrograph of a Cross Section on the 4 3/4" Test Plate.

PHASE IV TEST PLATE #7

Figure A-59. Macro Photo of Narrow Gap Sub Arc Weld - Plate IV-7

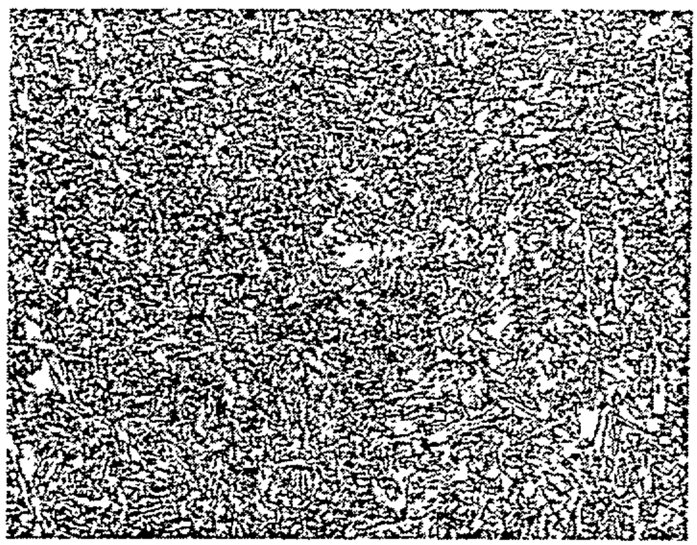

Figure No. 2 Mag: 500X Etch: 2% Nital

Weld microstructure; fine-grained ferrite with
a small percentage of pearlite.

PHASE IV TEST PLATE #7

Figure A-60. Microstructure of Weld - Plate IV-7

DATA NOT AVAILABLE

Figure A-61. Impact Tests of Plate IV-7

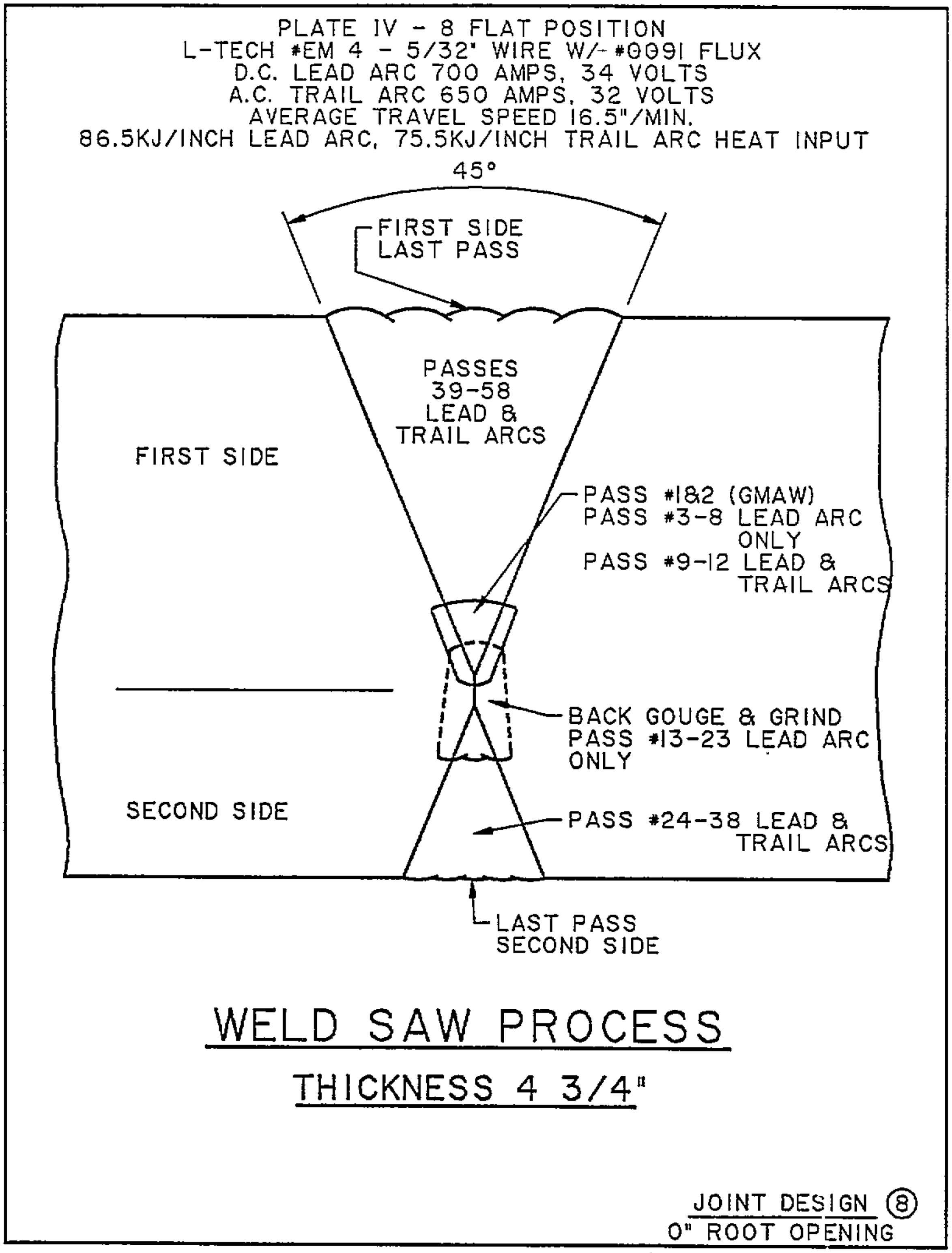

Figure A-62. Sub Arc Test Assembly for 4-3/4-Inch Thick 100 ksi Yield Strength Steel Plate

SOUTHWESTERN LABORATORIES

REPORT OF TESTS ON METAL SPECIMENS

FILE NO. 4092300

Beaumont TEXAS 6/23/88

TO: Bethlehem Steel Corporation — REPORT NO. 94307-je

PROJECT Mechanical Testing of Welding Procedure — ORDER NO. S-8805-1012

Req. No. 0230-0008

MATERIAL A-710, Grade A, Class 3, 4-3/4" thick

IDENTIFICATION Process: SAW

SPEC. REFERENCE ASME Sec. IX, SWL No. 9706-103-75 Rev. 1

Specimen	Size	Sq. In. Area	Yield, p.s.i.*	Ultimate Strength, lbs.	Tensile Strength, p.s.i.	% El.	% R.A.	Location of Fracture
EQUIRED:								
T-1	.755 x 1.018	.7685	100,183	87,500	113,844			Parent Metal
T-2	.748 x .936	.7001	105,984	78,900	112,698			Weld Metal
T-3 11 weld)	.502" dia.	.1979	89,944	21,940	110,864	26%	65%	

Side Bend #1 - Satisfactory

Side Bend #2 - Satisfactory

Side Bend #3 - Satisfactory

Side Bend #4 - Satisfactory

CHNICIAN: John Blair

PIES TO: 2-John West

SOUTHWESTERN LABORATORIES

PHASE IV - PLT 8

Figure A-63. Tensile and Bend Tests for Plate IV-8

241-O

SOUTHWESTERN LABORATORIES

FORT WORTH DALLAS HOUSTON MIDLAND BEAUMONT TEXARKANA

FILE No. 4092300

Beaumont TEXAS, 6/23/88

IMPACT TESTS ON STEEL

'o Bethlehem Steel Corporation

'. O. No. S-8805-1012 Date of Test 6/21/88

Material A-710 Grade A, Class 3, 4-3/4" thick

dentification Marks Process: S.A.W.

Specifications ASTM A-370, SWL No. 9706-102-75 Rev. 2

Testing Machine: T.O. Ser. # 88440 Test Method: "V" Notch Simple Charpy
Linear Velocity of Hammer: 16.8 ft. per second
Effective Energy: 264 ft. pounds Specimen Type: "A"
Specimen Size: 10mm x 10mm Specimen Temp: Minus 60° F.

pecimen dentification		Width, In Inches	Effective Section Size, In Inches	Impact Value Ft. Pounds	Lateral Exp. Mills	% Shear
Weld	#1	.393	.315	13	3	20
	#2	.393	.315	12.5	2	20
	#3	.394	.315	11.5	1	10
sion Line is 1mm	#1	.394	.315	108	46	40
	#2	.394	.315	71	25	20
	#3	..394	.315	36	8	10
sion Line is 5mm	#1	.394	.315	119	59	90
	#2	.394	.315	147	62	90
	#3	.394	.315	113	58	80

Copies: John West

SOUTHWESTERN LABORATORIES

PER Jack W. Durrell

PHASE IV - PLT 8

Lab. No. 99315-je

Figure A-64. Impact Tests of Plate IV-8

241-O'

SOUTHWESTERN LABORATORIES

FORT WORTH DALLAS HOUSTON MIDLAND BEAUMONT TEXARKANA

FILE No. 4090305

Beaumont TEXAS 9-16-88

IMPACT TESTS ON STEEL

To Bethlehem Steel Corporation

P. O. No. Date of Test 9-14-88

Material A-710 Class 3 Grade A, 4 3/4" tk

Identification Marks S.A.W. (Regular Weld Groove)

Specifications ASTM A-370 SWL No 9706-102-75 Rev. 1

Testing Machine: T.O. Ser. # 88440 Test Method: "V" Notch Simple Beam Charpy
Linear Velocity of Hammer: 16.8 ft. per second
Effective Energy: 264 ft. pounds Specimen Type: "A"
Specimen Size: 10mm X 10mm Specimen Temp: minus 40°F

Specimen Identification	Width, In Inches	Effective Section Size, In Inches	Impact Value Ft. Pounds	Lateral Exp. Mills	% Shear
Weld #1	.394	.315	22	20	20
#2	.394	.315	22	16	20
#3	.395	.315	40	30	20

Copies: 2-John West

Technician: John Blair

SOUTHWESTERN LABORATORIES

PER John B. Blair

PHASE IV - PLT 8

Lab. No. 94598-rg

Figure A-65. Impact Tests of Weld Metal for Plate IV-8 at -40 Degrees F

241-D

SOUTHWESTERN LABORATORIES

FORT WORTH DALLAS HOUSTON MIDLAND BEAUMONT TEXARKANA

FILE NO. 4092300

Beaumont, TEXAS 8/16/88

IMPACT TESTS ON STEEL

To Bethlehem Steel Corporation

P. O. No. S-8805-1012 Date of Test 8/16/88

Material A-710 Class 3, Grade A Modified, 4-3/4" thick

Identification Marks SAW

Specifications ASTM A-370, SWL No. 9706-102-75 Rev. 2

Testing Machine: T.O. Ser. # 88440 Test Method: "V" Notch Simple Charpy
Linear Velocity of Hammer: 16.8 ft. per second
Effective Energy: 264 ft. pounds Specimen Type: "A"
Specimen Size: 10mm x 10mm Specimen Temp: Minus 20° F.

Specimen Identification	Width, In Inches	Effective Section Size, In Inches	Impact Value Ft. Pounds	Lateral Exp. Mills	% Shear
Weld #1	.394	.314	22	17	20
#2	.394	.315	18	15	20
#3	.395	.315	21	18	20

Reference: 99315

Copies: John West

SOUTHWESTERN LABORATORIES

PER John B. Blan

PHASE IV - PLT 8

Lab. No. 94534-je

Figure A-66. Impact Tests of Weld Metal for Plate IV-8 at -20 Degrees F

241-D

SOUTHWESTERN LABORATORIES

FORT WORTH DALLAS HOUSTON MIDLAND BEAUMONT TEXARKANA

FILE NO. 4090305

Beaumont, TEXAS 9-16-88

IMPACT TESTS ON STEEL

To Bethlehem Steel Corporation

P. O. No. Date of Test 9-14-88

Material A-710 Class 3 Grade A, 4 3/4" tk

Identification Marks S.A.W. (Regular Weld Groove)

Specifications ASTM A-370 SWL No. 9706-102-75 Rev. 1

Testing Machine: T.O. Ser. # 88440 Test Method: "V" Notch Simple Beam Charpy
Linear Velocity of Hammer: 16.8 ft. per second
Effective Energy: 264 ft. pounds Specimen Type: "A"
Specimen Size: 10mm X 10mm Specimen Temp: 0°F

Specimen Identification	Width, In Inches	Effective Section Size, In Inches	Impact Value Ft. Pounds	Lateral Exp. Mills	% Shear
Weld #1	.395	.315	43	32	30
#2	.395	.315	51	39	20
#3	.395	.315	61	48	30

Copies: 2-John West

Technician: John Blair

Lab. No. 94596-rg

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PER John B. Blair

PHASE IV - PLT 8

Figure A-67. Impact Tests of Weld Metal for Plate IV-8 at 0 Degrees F

PHOTOMACROGRAPH OF PHASE IV

TEST PLATE NO. 8

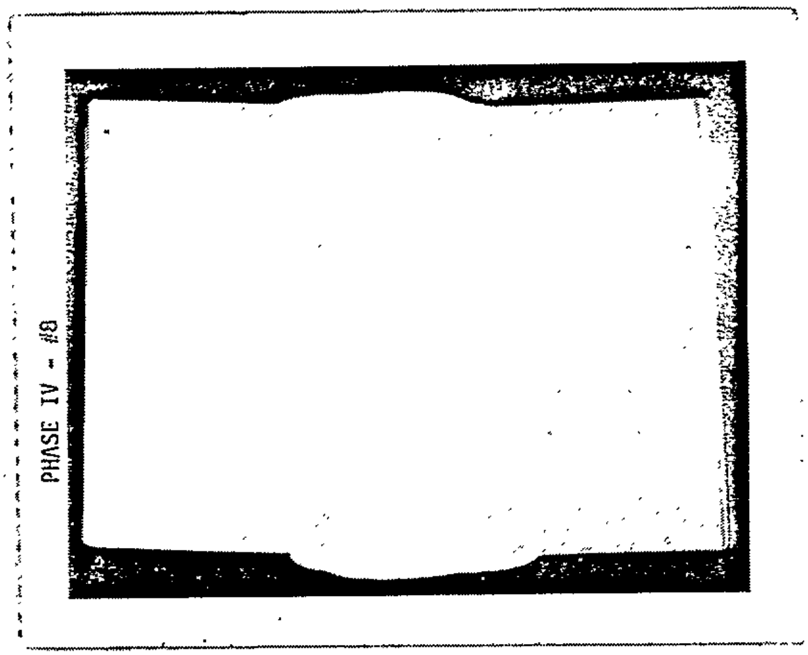

Figure A-68. Macro Photo of 4-3/4-Inch Thick Sub Arc Weld - Test Plate IV-8

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BETHLEHEM STEEL CORPORATION

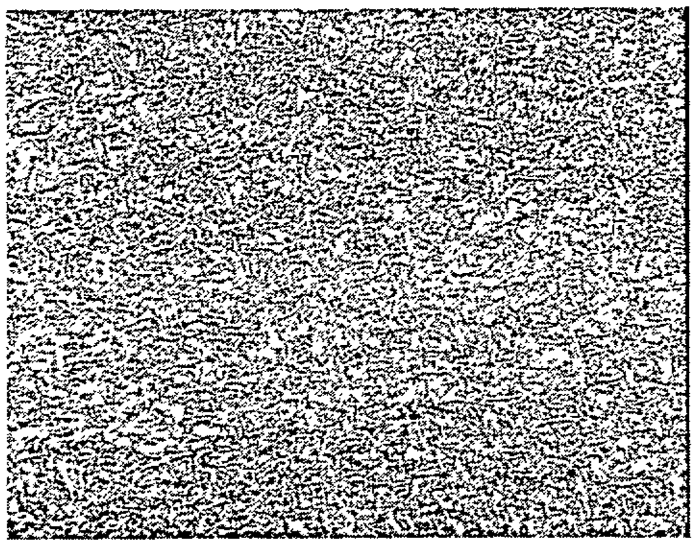

Figure No. 1 2% Nital

Microstructure at 500X in weld metal on Sample No. 1.

PHASE IV TEST PLATE #8

Figure A-69. Microstructure of 4-3/4-Inch Thick Sub Arc Weld - Plate IV-8

SOUTHWESTERN LABORATORIES
BETHLEHEM STEEL CORPORATION

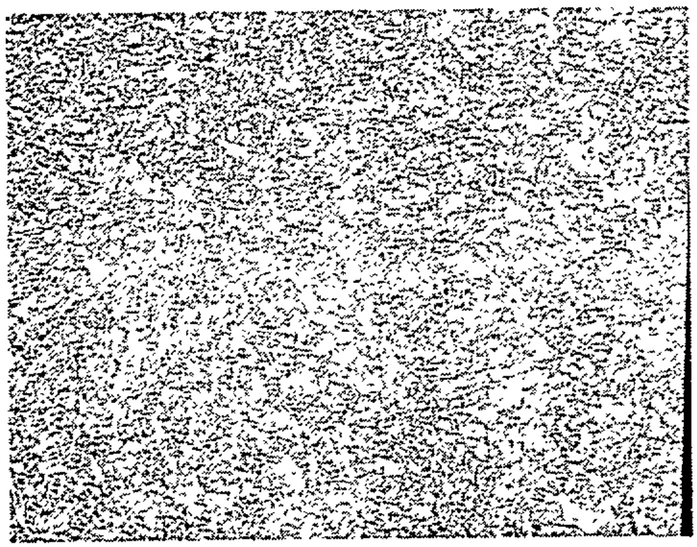

Figure No. 2 2% Nital

Microstructure at 320X near the fusion zone with the photo primarily showing the HAZ on Sample No. 1

PHASE IV TEST PLATE #8

Figure A-70. Microstructure of 4-3/4-Inch Thick Sub Arc Weld Near Fusion Line - Plate IV-8

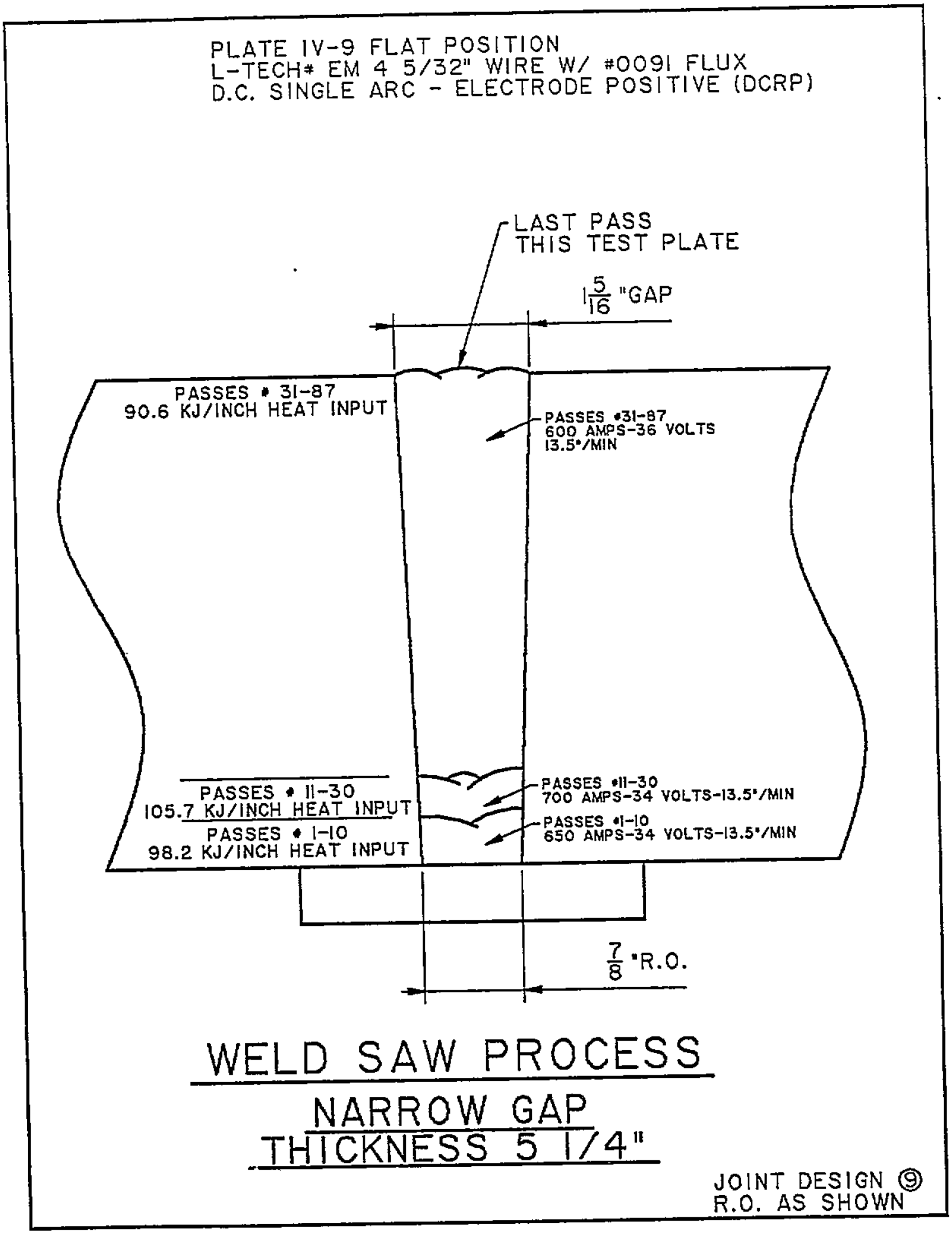

Figure A-71. Narrow Gap Sub Arc Weld of 5-1/4-Inch Thick
100 ksi Yield Strength Steel Plate IV-9

SOUTHWESTERN LABORATORIES

REPORT OF TESTS ON METAL SPECIMENS

FILE NO. 4092300

Beaumont TEXAS 8/16/88

REPORT NO. 94533-je

ORDER NO. S-8805-1012

TO: Bethlehem Steel Corporation

PROJECT Mechanical Testing of Welding Procedure

MATERIAL A710, Class 3, Grade A Modified, 5-1/4" thick

IDENTIFICATION SAW, Narrow Gap

SPEC. REFERENCE ASME Sec. IX, SWL No. 9706-103-75 Rev. 1

Specimen	Size	Sq. In. Area	Yield, p.s.i.*	Ultimate Strength, lbs.	Tensile Strength, p.s.i.	% El.	% R.A.	Location of Fracture
REQUIRED:								
T-1	.747 x .969	.7238	107,067	83,400	115,225			Weld Metal
T-2	.759 x .992	.7529	97,489	86,900	115,416			Weld Metal
T-3 (All weld)	.494" dia.	.1917	103,547	21,440	111,841	13.5%	26%	

Side Bend #1 - Unsatisfactory

Side Bend #2 - Unsatisfactory

Side Bend #3 - Satisfactory

Side Bend #4 - Satisfactory

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TECHNICIAN: John Blair

COPIES TO: 2--John West

SOUTHWESTERN LABORATORIES

John B. Blair

PHASE IV - PLT. 9

Figure A-72. Tensile and Bend Tests for Plate IV-9

241-O

SOUTHWESTERN LABORATORIES

FORT WORTH DALLAS HOUSTON MIDLAND BEAUMONT TEXARKANA

FILE No. 4092300

Beaumont TEXAS 8/19/88

IMPACT TESTS ON STEEL

To Bethlehem Steel Corporation

P. O. No. S-8805-1012 Date of Test 8/16/88

Material A-710 Class 3, Grade A Modified, 5-1/4" thick

Identification Marks SAW, Narrow Gap

Specifications ASTM A-370, SWL No. 9706-102-75 Rev. 2

Testing Machine: T.O. Ser. # 88440 Test Method: "V" Notch Simple Charpy
Linear Velocity of Hammer: 16.8 ft. per second
Effective Energy: 264 ft. pounds Specimen Type: "A"
Specimen Size: 10mm x 10mm Specimen Temp: Minus 60° F.

Specimen Identification		Width, In Inches	Effective Section Size, In Inches	Impact Value Ft. Pounds	Lateral Exp. Mills	% Shear
Weld	#1	.394	.315	12.5	8	20
	#2	.394	.315	16.0	11	20
	#3	.394	.315	19.0	12	20
usion Line · 1 mm	#1	.393	.315	140.0	72	50
	#2	.394	.315	142.0	65	60
	#3	.394	.315	174.0	55	50
usion Line · 5 mm	#1	.394	.315	109.0	60	20
	#2	.394	.315	34.0	25	30
	#3	.394	.315	54.0	29	20

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PER John B. [illegible]

PHASE IV - PLT 9

Lab. No. 99487-je

Figure A-73. Impact Tests for Plate IV-9 at -60 Degrees F

24¥-D

SOUTHWESTERN LABORATORIES

FORT WORTH DALLAS HOUSTON MIDLAND BEAUMONT TEXARKANA

FILE NO. 4092300

Beaumont TEXAS, 9-23-88

IMPACT TESTS ON STEEL

To Bethlehem Steel Corporation

P. O. No. S-8805-1012, Req. No. 0230-0008 Date of Test 9-22-88

Material A-710 Class 3 Grade A, 5 1/4" tk.

Identification Marks S.A.W. Narrow Gap

Specifications ASTM A-370, SWL No. 9706-102-75 Rev. 2

Testing Machine: T.O. Ser. # 88440 Test Method: "V" Notch Simple Beam Charpy
Linear Velocity of Hammer: 16.8 ft. per second
Effective Energy: 264 ft. pounds Specimen Type: "A"
Specimen Size: 10mm X 10mm Specimen Temp: minus 40°F

Specimen Identification	Width, In Inches	Effective Section Size, In Inches	Impact Value Ft. Pounds	Lateral Exp. Mills	% Shear
Weld #1	.395	.315	27	17	20
#2	.395	.315	26.5	19	20
#3	.395	.315	33.5	22	20

27

Copies: 2-John West

Technician: John Blair

SOUTHWESTERN LABORATORIES

PER John B. Blair

PHASE IV - PLT 9

Lab. No. 94579-rg

Figure A-74. Impact Tests for Plate IV-9 at -40 Degrees F

241-D

SOUTHWESTERN LABORATORIES

FORT WORTH DALLAS HOUSTON MIDLAND BEAUMONT TEXARKANA

FILE NO. 4092300

Beaumont, TEXAS, 8/19/88

IMPACT TESTS ON STEEL

To: Bethlehem Steel Corporation

P. O. No. S-8805-1012 Date of Test 8/16/88

Material A-710, Class 3, Grade A Modified, 5-1/4" thick

Identification Marks SAW Narrow Gap

Specifications ASTM A-370, SWL No. 9706-102-75 Rev. 2

Testing Machine: T.O. Ser. # 88440 Test Method: "V" Notch Simple Charpy
Linear Velocity of Hammer: 16.8 ft. per second
Effective Energy: 264 ft. pounds Specimen Type: "A"
Specimen Size: 10mm x 10mm Specimen Temp: Zero °F.

Specimen Identification	Width, In Inches	Effective Section Size, In Inches	Impact Value Ft. Pounds	Lateral Exp. Mills	% Shear
Weld #1	.393	.315	52	30	40
#2	.393	.315	34	24	30
#3	.393	.315	55	30	40

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AUG 24 1988
E... DEPT.

Copies: 2-John West

SOUTHWESTERN LABORATORIES

PER John B. Blair

PHASE IV - PLT 9

Lab. No. 94536-je

Figure A-75. Impact Tests for Plate IV-9 at 0 Degrees F

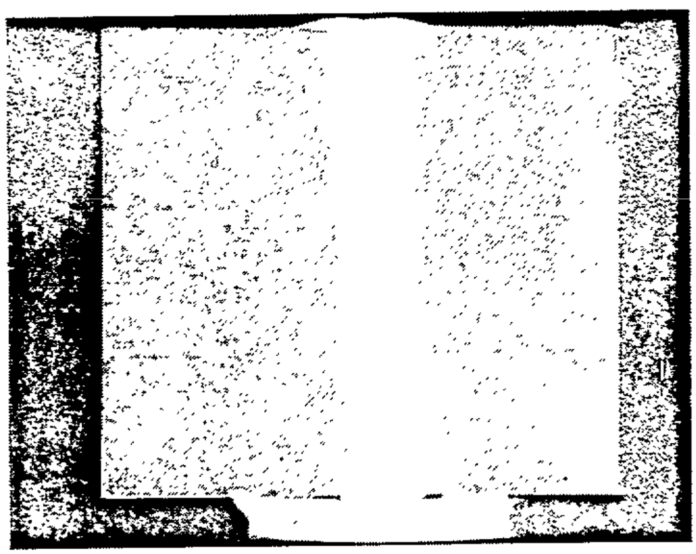

Figure No. 3 Mag: 0.6X Etch: 2% Nital

Photomacrograph of a cross section on the 5 1/4" test plate.

PHASE IV TEST PLATE #9

Figure A-76. Macro Photo of Plate IV-9

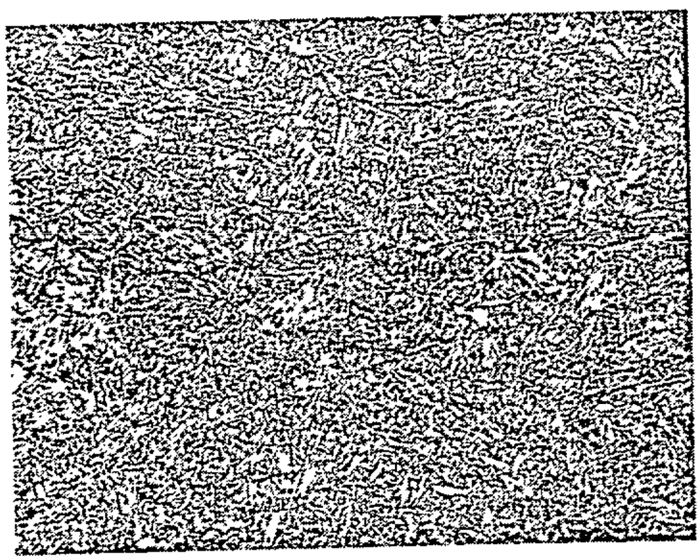

Figure No. 4 Mag: 500X Etch: 2% Nital
PHASE IV TEST PLATE #9
Weld microstructure; fine-grained ferrite with a small percentage of pearlite.

SOUTHWESTERN LABORATORIES

Dennis Stanfield
Reviewed By

York Patterson

ckl

Figure A-77. Weld Microstructure Plate IV-9

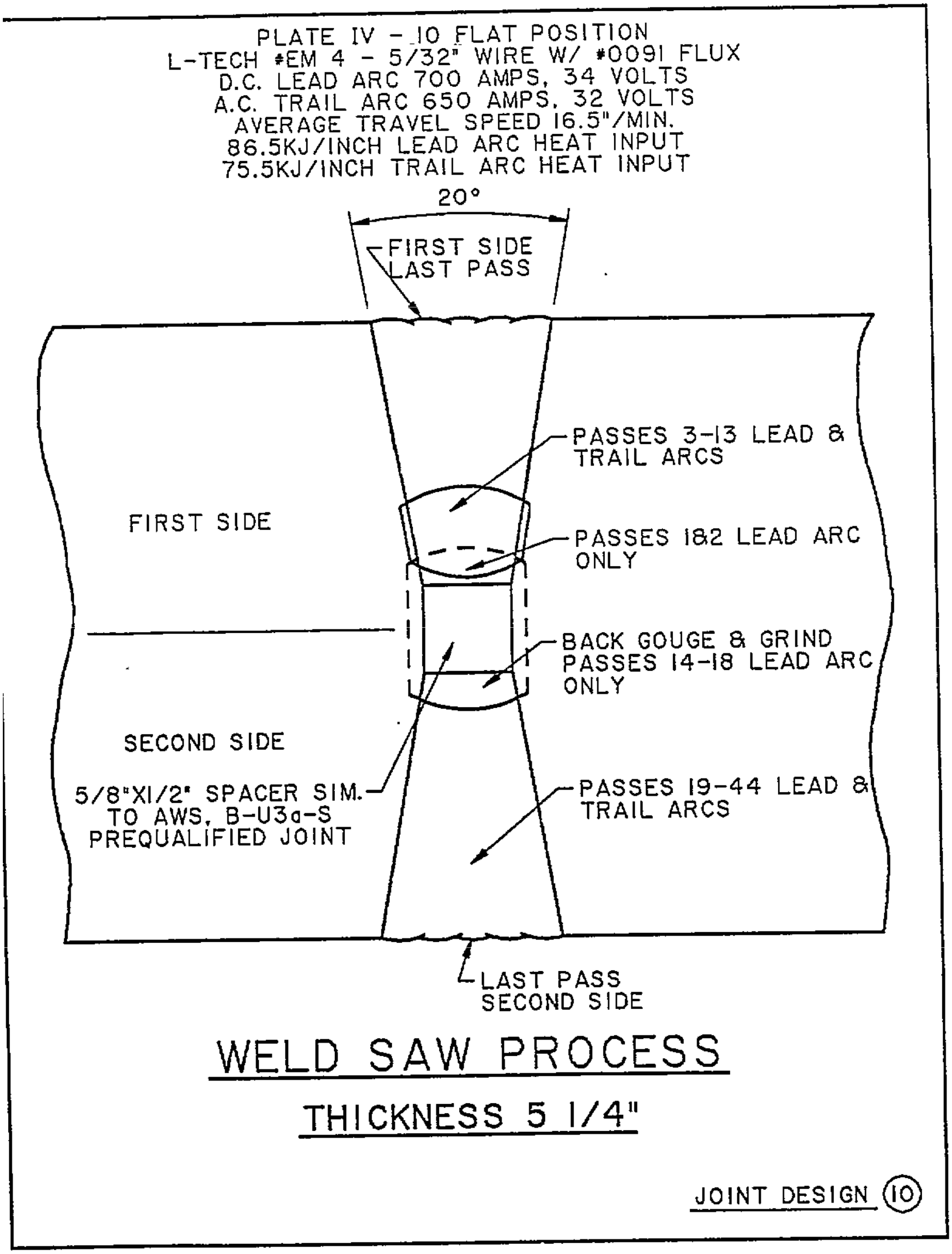

Figure A-78. Dual Sub Arc Weld of 5-1/4-Inch Thick
100 ksi Yield Strength Steel Plate IV-10

SOUTHWESTERN LABORATORIES

REPORT OF TESTS ON METAL SPECIMENS

FILE NO. 4092300

BEaumont TEXAS 7/26/88

TO: Bethlehem Steel Corporation

REPORT NO. 99313-je

PROJECT Mechanical Testing of Welding Procedure

ORDER NO. S-8805-1012
Req. No. 0230-0008

MATERIAL A-710, Grade A, Class 3 Modified, 5-1/4" thick

IDENTIFICATION SAW

SPEC. REFERENCE ASME Sec. IX, SWL NO. 9706-103-75 Rev. 1

Specimen	Size	Sq. In. Area	Yield, p.s.i.*	Ultimate Strength, lbs.	Tensile Strength, p.s.i.	% El.	% R.A.	Location of Fracture
REQUIRED:								
T-1	.753 x 1.003	.7552	88,049	84,700	112,146			Parent Metal
T-2	.745 x 1.008	.7509	93,746	81,600	108,660			Weld Metal
T-3 (All weld)	.508" dia.	.2027	79,921	22,490	110,952	25.5%	65%	

Side Bend #1 - Satisfactory

Side Bend #2 - Satisfactory

Side Bend #3 - Satisfactory

Side Bend #4 - Satisfactory

TECHNICIAN: John Blair

COPIES TO: 2-John West

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SOUTHWESTERN LABORATORIES

John B. Blair

PHASE IV - PLT 10

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Figure A-79. Tensile and Bend Tests for Plate IV-10

241-D

SOUTHWESTERN LABORATORIES

FORT WORTH DALLAS HOUSTON MIDLAND BEAUMONT TEXARKANA

FILE No. 4092300

Beaumont TEXAS 7/29/88

IMPACT TESTS ON STEEL

To Bethlehem Steel Corporation

P. O. No. S-8805-1012 Req. No. 0230-0008 Date of Test 7/26/88

Material A-710, GRAde A, Class 3 Modified, 5-1/4" thick

Identification Marks SAW

Specifications ASTM A-370, sWL No. 9706-102-75 Rev. 2

Testing Machine: T.O. Ser. # 88440 Test Method: "V" Notch Simple Charpy
Linear Velocity of Hammer: 16.8 ft. per second
Effective Energy: 264 ft. pounds Specimen Type: "A"
Specimen Size: 10mm x 10mm Specimen Temp: Minus 60° F.

Specimen Identification		Width, In Inches	Effective Section Size, In Inches	Impact Value Ft. Pounds	Lateral Exp. Mills	% Shear
Weld #1		.394	.315	18	10	20
#2		.394	.315	13	7	20
#3		.394	.315	14	9	10
Fusion Line + 1mm	#1	.394	.315	70	35	20
	#2	.394	.315	116	60	30
	#3	.394	.315	101	53	30
Fusion Line + 5mm	#1	.394	.315	100	60	30
	#2	.394	.315	117	67	40
	#3	.394	.315	102	60	40

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PER John B. Blair

PHASE IV - PLT 10

Lab. No. 99470-je

Figure A-80. Impact Tests for Plate IV-10 at -60 Degrees F

241-D

SOUTHWESTERN LABORATORIES

FORT WORTH DALLAS HOUSTON MIDLAND BEAUMONT TEXARKANA

FILE No. 4090305

Beaumont TEXAS 9-16-88

IMPACT TESTS ON STEEL

To: Bethlehem Steel Corporation

P. O. No. ______ Date of Test 9-14-88

Material: A-710 Class 3 Grade A, 5 1/4" tk

Identification Marks: S.A.W. (Regular Weld Groove)

Specifications: ASTM A-370 SWL No. 9706-102-75 Rev. 1

Testing Machine: T.O. Ser. # 88440 Test Method: "V" Notch Simple Beam Charpy

Linear Velocity of Hammer: 16.8 ft. per second

Effective Energy: 264 ft. pounds Specimen Type: "A"

Specimen Size: 10mm X 10mm Specimen Temp: minus 40°F

Specimen Identification	Width, In Inches	Effective Section Size, In Inches	Impact Value Ft. Pounds	Lateral Exp. Mills	% Shear
Weld #1	.395	.315	23	22	20
#2	.395	.314	14.5	13	10
#3	.395	.315	20	16	20

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Copies: 2-John West

Techician: John Blair

Lab. No. 94597-rg

SOUTHWESTERN LABORATORIES

PER John B. Blair

PHASE IV - PLT 10

Figure A-81. Impact Tests for Plate IV-10 at -40 Degrees F

241-D

SOUTHWESTERN LABORATORIES

FORT WORTH DALLAS HOUSTON MIDLAND BEAUMONT TEXARKANA

FILE NO. 4092300

Beaumont TEXAS 9-26-88

IMPACT TESTS ON STEEL

To Bethlehem Steel Corporation

P. O. No. Date of Test 9-23-88

Material A-710 Class 3 Grade A, 5 1/4"tk

Identification Marks S.A.W. (Regular Weld Groove)

Specifications ASTM A-370, SWL No. 9706-102-75 Rev. 2

Testing Machine: T.O. Ser. # 88440 Test Method: "V" Notch Simple Beam Charpy
Linear Velocity of Hammer: 16.8 ft. per second
Effective Energy: 264 ft. pounds Specimen Type: "A"
Specimen Size: 10mm X 10mm Specimen Temp: minus 40°F

Specimen Identification	Width, In Inches	Effective Section Size, In Inches	Impact Value Ft. Pounds	Lateral Exp. Mills	% Shear
Weld #1	.394	.315	21.0	17	20
#2	.394	.315	12.0	9	10

Copies: 2-Joe West

Technician: John Blair

Lab. No. 94610-rg

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ENGINEERING

SOUTHWESTERN LABORATORIES

PER John B. Blair

Phase IV PLT-10

Figure A-82. Additional Impact Tests for Plate IV-10 at -40 Degrees F

241-D

SOUTHWESTERN LABORATORIES

FORT WORTH DALLAS HOUSTON MIDLAND BEAUMONT TEXARKANA

FILE NO. 4090305

Beaumont TEXAS 9-16-88

IMPACT TESTS ON STEEL

To Bethlehem Steel Corporation

P. O. No. ______ Date of Test 9-14-88

Material A-710 Class 3 Grade A, 5 1/4" tk

Identification Marks S.A.W. (Regular Weld Groove)

Specifications ASTM A-370 SWL No. 9706-102-75 Rev. 1

Testing Machine: T.O. Ser. # 88440 Test Method: "V" Notch Simple Beam Charpy
Linear Velocity of Hammer: 16.8 ft. per second
Effective Energy: 264 ft. pounds Specimen Type: "A"
Specimen Size: 10mm X 10mm Specimen Temp: minus 20°F

Specimen Identification	Width, In Inches	Effective Section Size, In Inches	Impact Value Ft. Pounds	Lateral Exp. Mills	% Shear
Weld #1	.395	.315	31	28	30
#2	.395	.315	28	24	20
#3	.395	.315	31	25	20

Copies: 2-John West

Technician: John Blair

Lab. No. 94593-rg

SOUTHWESTERN LABORATORIES

PER John B. Blair
PHASE IV - PLT 10

Figure A-83. Impact Tests for Weld Metal at -20 Degrees Plate IV-10

241-D

SOUTHWESTERN LABORATORIES

FORT WORTH DALLAS HOUSTON MIDLAND BEAUMONT TEXARKANA

FILE No. 4092300

Beaumont, TEXAS, 8/19/88

IMPACT TESTS ON STEEL

To Bethlehem Steel Corporation

P. O. No. S-8805-1012 Date of Test 8/16/88

Material A-710, Class 3, Grade A Modified, 5-1/4" thick

Identification Marks SAW

Specifications ASTM A-370, SWL No. 9706-102-75 Rev. 2

Testing Machine: T.O. Ser. # 88440 Test Method: "V" Notch Simple Charpy
Linear Velocity of Hammer: 16.8 ft. per second
Effective Energy: 264 ft. pounds Specimen Type: "A"
Specimen Size: 10mm x 10mm Specimen Temp: Minus 10° F.

Specimen Identification	Width, In Inches	Effective Section Size, In Inches	Impact Value Ft. Pounds	Lateral Exp. Mills	% Shear
Weld #1	.394	.315	27	19	20
#2	.394	.315	31	22	30
#3	.394	.315	23	19	20

Reference: 99470

Copies: John West

SOUTHWESTERN LABORATORIES

PER John B. Blain

PHASE IV - PLT 10

Lab. No. 94535-je

Figure A-84. Impact Tests for Plate IV-10 at -10 Degrees F

PHOTOMACROGRAPH OF PHASE IV

TEST PLATE NO. 10

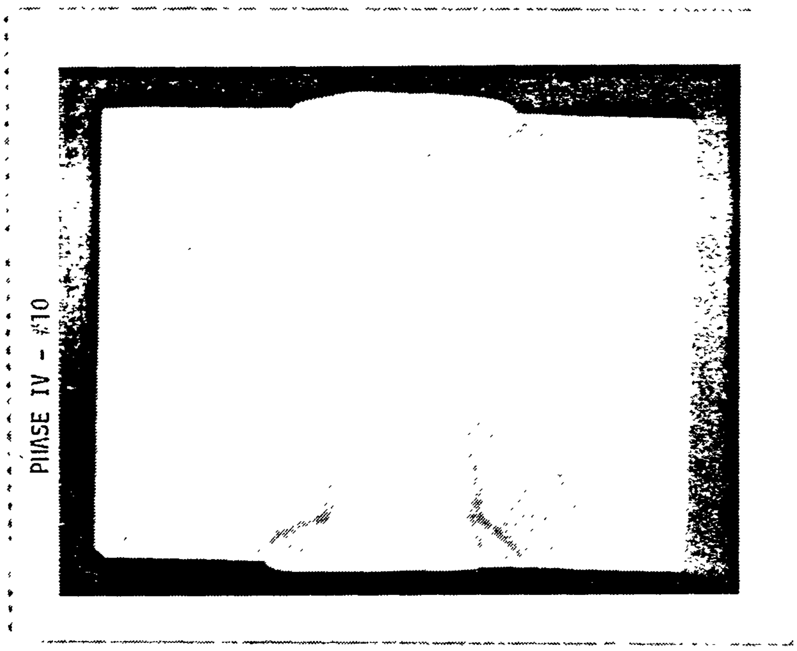

Figure A-85. Macro Photo of Plate IV-10

SOUTHWESTERN LABORATORIES
BETHLEHEM STEEL CORPORATION

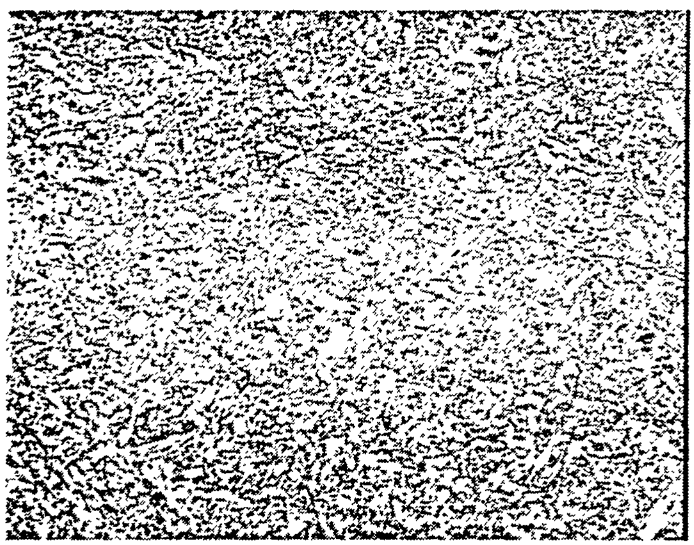

Figure No. 3 2% Nital

Microstructure at 500X in the weld metal on Sample No. 2.

PHASE IV TEST PLATE #10

Figure A-86. Microstructure of Sub Arc Weld - Plate IV-10

SOUTHWESTERN LABORATORIES
BETHLEHEM STEEL CORPORATION

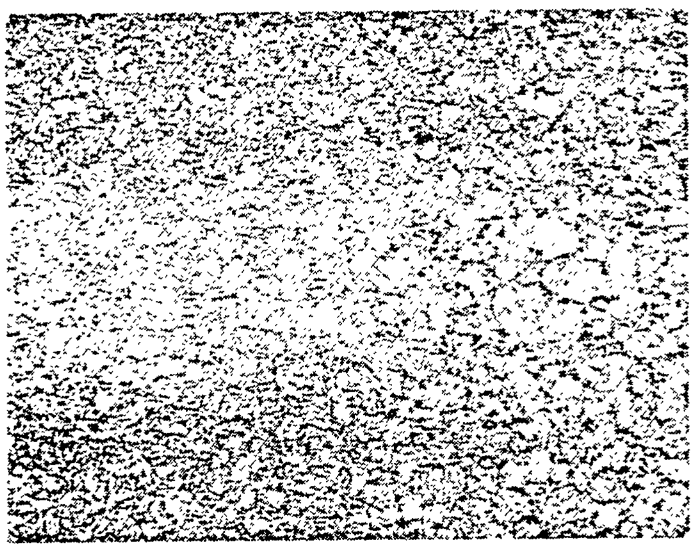

Figure No. 4 2% Nital

Microstructure at 320X near the fusion zone with the photo showing primarily HAZ on Sample No. 2.

PHASE IV TEST PLATE #10

Figure A-87. Microstructure of Plate IV-10 Near Fusion Line

BETHLEHEM STEEL-BEAUMONT YARD TELEPHONE MEMORANDUM

Call Originated By:	Time:	Date:
J. C. West	1:45 PM	11-4-88

Conversation With: Subject:
Dave Myer, L-Tee (216)992-1271 AWS 5.23 - F11A6-EM4-M4 Wire/Flux

Distribution:
JCW.B555Blalc

Memorandum Re Conversation:

WEST TO MYER

L-Tech's "Welding and Cutting Systems Catalog" F3307N, 9/86, page 10-27 shows L120 wire with 0091 flux would meet AWS 5.23, F11A6-EM4-M4 classification. Page 10-26 shows this combination produces charpy notch values of 56 ft.llbs. at O°F and 32 ft./lbs. at -60°F when welding parameters of AWS 5.23, Figure 2, whose maximum heat input is 65.1 KJ/in. are used. We had exceeded the parameters in welding eight (8) plates and were unable to attain L-Tee's indicated values. However, one welded at 198.1 KJ/in. had an average of 20 ft./lbs. at -60"F and one welded at 83.1 KJ/in. reached 21 ft./lbs. Our best O"F reading was 52 ft.fibs. at 162 KJ/in. Macro and micrograph showed excellent to good grain structures in every case. Analysis of the wire versus the deposit showed a drop of .61 Mn, from 1.62 to 1.01. Table 2 of AWS 5.23 specifies Mn4 deposit to be 1.30/2.25, therefore, this combination does not meet the AWS 5.23 specification. What is wrong?

MYER TO WEST

1. The data on page 10-27 of the L-Tee catalog is incorrect. It should read F11A6-EM4-G. The M4 call out needs to be corrected. AWS 5.23 Table 2, M4 specifications cannot be applied to a "G" deposit.

2. The quoted charpys may *or* may not be met when using the quoted parameters, this is an EM4 wire with a "G" deposit which is determined by the flux, althougH, it is a calcium-silicate "neutral" compound.

3. L-Tee now has a L-133 wire and #633 flux that meets Mil. Spec. 23165/2D that can be used to weld HY-1OO without experiencing the above problems.

Figure A-88. Cause of Low Toughness of 100 ksi Yield Strength Welds

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Attention: SwL - Beaumont / Mr. John Blair
Bethlehem Steel Corporation

Report No: 22859
File No: 4092300
Date: 10/21/88
SwL-Beaumont Report No: 94659

Project: Chemical Analysis of Wire

PROJECT INFORMATION

Material:	5/32" Wire and 1/8" Wire		
Identification:	Sample 1 - 1/8" Wire, Sample 2 - 5/32" Wire		
Date Received:	October 18, 1988	*Technician:*	Bob Yount & Del Armstrong
Specifications:	EM-4 5.23	*Date of Test:*	October 20, 1988
Test Equipment:	Siemens SRS-200 XRF, Leco IR-12 Carbon	*Procedure:*	ASTM E 322, E 1019

CHEMICAL COMPOSITION (WT. %)

Specimen Identification	C	Mn	P	S	Si	Ni	Cr	Mo	V
1 (1/8" Wire)	0.07	1.61	0.017	<0.005	0.35	2.33	0.30	0.47	<0.01
2 (5/32" Wire)	0.08	1.62	0.015	<0.005	0.35	2.31	0.29	0.46	<0.01

Specimen Identification	Cu	Al	Ti	Zr
1 (1/8" Wire)	0.03	0.021	0.01	0.01
2 (5/32" Wire)	0.03	0.011	0.01	0.01

OCT 25

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Figure A-89. Chemical Analysis of Weld Wire Used in Phase IV

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Attention: *SwL - Beaumont / Mr. John Blair*
Bethlehem Steel

Report No: 22768
File No:
Date: 10/07/88
QA PRS No: 94638

Project: Chemical Analysis of Steel Alloy

PROJECT INFORMATION

Material:	One - 4-1/2" Thick Regular Gap Weld Test Plate		
Identification:	As Per 21-09-94638		
Date Received:	September 30, 1988	*Technician:*	Bob Yount, Del Armstrong
Specifications:	N/A	*Date of Test:*	Sept. 30 to October 03, 1988
Test Equipment:	Siemens SRS-200 XRF, Leco IR-12 Carbon	*Procedure:*	ASTM E 322, E 1019

CHEMICAL COMPOSITION (WT. %)

Specimen Identification	C	Mn	Si	Ni	Cr	Mo	Cu
94638	0.08	1.10	0.52	2.14	0.27	0.47	0.18

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tda

Reviewed By

Figure A-90. Chemical Analysis of Weld Deposit

PHASE IV

SUBMERGED ARC PLATES - DEPOSITED WELD METAL ANALYSIS

Plate No.	2	4	5	6	7	8	9	10
Thickness (")	3-1/4	3-3/4	4-1/4	4-1/4	4-3/4	4-3/4	5-1/4	5-1/4
Total K/J in.	198.1	198.1	88.8	204.1	83.1	162	90.6	162
Lead Arc AxV	700x34	700x34	500x32	700x35	550x34	700x34	600x34	700x34
Trail Arc AxV	650x32	650x32	None	650x33	None	650x32	None	650x32
Speed, in./min.	13.5	13.5	10.8	13.5	13.5	16.5	13.5	16.5
Stickout, inch	1-1¼	1-1¼	1-1¼	1-1¼	1-1¼	1-1¼	1-1¼	1-1¼
Melt Rate								
Total lbs.	.5792	.5792	.2061	.5792	.2293	.5792	.2530	.5792
Per min.	.6023	.6023	.2121	.6023	.2366	.6023	.2618	.6023
Total Area								
Sq. in.	.5200	.5200	.1996	.5200	.1892	.4338	.2165	.4338
Dilution								
% of	.7153	.7153	.6528	.7153	.6730	.6990	.6838	.6990
Base Metal	.7225	.7225	.6625	.7225	.6831	.7101	.6944	.7101
Penetration								
Total Depth Inches	.5800	.5800	.2138	.5685	.2164	.5425	.2430	.5425
Charpy "V"								
-60°F Ft./Lbs.	19	20	12.6	11.2	21	12.3	16	15

Figure A-91. Correlation of Weld Deposit with Welding Parameters for Phase IV Test Plates

WIRE CHEMISTRY VS. DEPOSITED WELD METAL COMPARISON

Phase	III	IV
Class AWS 5.23	F10AL-EF6	F11A6-EM4-M4 (See Note)
Producer	Oerlikon	L-Tec
Grades	OP121TT Flux W-25 Wire	0091 Flux L-120 Wire

Chemistry	EF6	W-25	DEP.	+ or –	EM4	L120	DEP.	+ or –	M4
C	.07/.15	.09	.08	0	.10	.08	.073	–.007	.10
Mn	1.45/1.90	1.65	1.47	–.18	1.40/1.80	1.62	1.01	–.61	1.30/2.25
Si	.10/.30	.20	.25	+.05	.20/.60	.35	.59	+.24	.80
Cr	.20/.55	.35	.41	+.06	.60	.29	.27	–.02	.65
Ni	1.75/2.25	1.65	1.75	+.10	2.00/2.80	2.31	2.16	–.15	2.00/2.80
Mo	.40/.65	.50	.50	0	.30/.65	.46	.47	+.01	.30/.80
Cu	.35	.17	.18	+.01	.25	.03	.18	+.15	.30

NOTE: M4 Deposit shown in L-Tec literature is incorrect. Should be F11A6-EM4-G.
D. Myer, L-Tec to Bethlehem Steel-Beaumont, 11/4/88.

Figure A-92. Comparison of Weld Metal Chemistry with Weld Deposit Chemistry

DEPOSITED WELD METAL ANALYSIS

AWS 5.23 Classification for L-Tec 120 Wire with 0091 Flux is F11A6-EX4-M4.

Figure 2 of AWS 5.23 provides the welding conditions for this classification of 5/32" wire.

Amps 500 ± 25	-	Range 475 to 525 A
Volts 30 ± 1	-	Range 29 to 31 V
Travel 16" ± 1	-	Range 15 to 17 in./min.
Stickout 1-1/4" ± 1/4	-	Range 1 to 1-1/2 in.

Empirical Formulae For Evaluating SAW Welds
AMS Handbook: Volume 6, Table 10, Page 137

Definitions

- MR = Electrode Melting Rate, lb./rein.
- A = Area of Weld Bead Sections, in.^{z}
- I = Welding Current, amperes
- L = Electrode Extension, inches
- d = Electrode Diameter, inches
- P = Arc Penetration, inches
- K = FIux constant, 0.0012 for Ca_ SiO. flux
- L = Welding Voltage, volts
- S = Travel Speed, in./min.
- D = Z Base Metal Dilution

Formulae are,

$$MR = \frac{I}{1000}\left[0.35 + d^{2} + 2.08 \times 10^{-7}\left(\frac{IL}{d^2}\right)^{1.22}\right] = \text{lb./min.}$$

$$A = \frac{11.55}{10^{3.95}\ S^{0.903}} = \text{square inches}$$

$$D = 100 - \frac{353MR}{AS} = \%\ \text{base metal}$$

$$P = K\ ^3\ I^4/SE^{2} = \text{inches}$$

Figure A-93. Method of Analysis of Welding Parameters and Weld Deposit for Phase IV Plates Using LTEC 120 Wire and Deposit LTEC0091 FIux (Sheet 1 of 2)

Substituting welding conditions of AWS 5.23 in each formula gives the following results.

MR at Max. kip 525, Flax. S10 1-1/2" = .23115 in.lmin.
Max. .hp 525, Min. S/0 1" = .21765 in./min.

Min. kp 475, Max. S/0 1-1/2" = .20554 in./min.
Min. Amp 475, Min. S/0 1" = .19473 in.lmin.

MR Range = .19473 to .ZS115 in./min.

A at Max. Amp 523, Min. Speed 15''/min. = .16U05 in.^{2}
Max. Amp 525, Max. Speed 17''/min. = .14300 in.^{2}

Min. Amp 475, Min. Speed 15''/min. = .13/00 in.^{2}
Min. Amp 475, Max. Speed 17''/min. = .12240 in.^{2}

A Range = .12240 to .16005 square inches

D = Flax. Amp 525, Min. S/0 l", Max. Speed 17" = 68.40 % Base Metal
Xax. Amp 525, llin. S/0 l", Min. Speed 15" = 67.98 Z Base Metal

Min. Amp 475, Min. S/0 l", Max. Speed 17" = 66.97 Z Base Metal
Min. bp 475, Min. S/0 1", Min. Speed 15" = 66.55 Z Base Metal

Max. Amp 525, Max. S/0 1-1/2", Max. Speed 17" = 66.44 Z Base Metal
Max. Amp 525, Max. S10 1-1/2", Min. Speed 15" = 66.00 % Base Hetal

Min. Amp 475, Max. S/0 1-1/2", Max. Speed 17" = 65.14 Z Base Metal
Min. Amp 475, Max. S/0 1-1/2", Min. Speed 15" = 64.70 % Base Metal

D Range = 64.70 to 68.40 Z Base Metal

P = Max. Amp 525, Min. V 29, Min. Speed 15" = .2183 in.
Max. Amp 525, Min. V 29, Max. Speed 17" = .2094 in.
Max. Amp 525, Max. V 31, Min. Speed 15" = .2088 in.
Max. Amp 525, Max. V 31, Max. Speed 17" = .2003 in.

Min. Amp 475, Min. V 29, Min. Speed 15" = .1910 in.
Min. Amp 475, Min. V 29, Max. Speed 17" = .1832 in.
Min. Amp 475, Max. V 31, Min. Speed 15" = .1827 in.
Min. Amp 475, Max. V 31, Max. Speed 17" = .1753 in.

P Range = .1753 to .2183 in.

Eeat Input Range 48618 to 65100 J/in.
AWS 5.23 Fig. 2 1913 to 2543 J/mm

Figure A-93. Method of Analysis of Welding Parameters and Weld Deposit for Phase IV Plates Using LTEC 120 Wire and Deposit LTECO091 Flux (Sheet 2 of 2)

LTEC
WELDING & CUTTING SYSTEMS

SUBMERGED ARC WELDING PRODUCTS

WELD METAL MECHANICAL PROPERTIES

Plate[a] Type 1 in. (25.4 mm) Thick	Stress Relief Time @ 1150°F (621°C)	Wire	UTS ksi	UTS mPa	YS ksi	YS mPa	% Elongation	% Reduction in area	CVN — ft-lb. (J) 30°F (-1°C)	10°F (-12°C)	0°F (-18°C)	-20°F (-29°C)	-40°F (-40°C)	-60°F (-51°C)
L-TEC 709-5 FLUX														
A204	AW	L-TEC 40B	83	570	72	495	25	68	—	—	—	35 (47)	21 (28)	—
	8 hr.	L-TEC 40B	78	525	63	435	30	71	—	—	—	59 (80)	—	—
A588	AW	L-TEC WS	88	595	72	495	25	60	—	—	—	44 (60)	—	—
A537	AW	L-TEC EN54	90	620	74	510	26	68	—	—	—	38 (51)	31 (42)	—
T-1	AW	L-TEC 100	118	815	106	730	20	58	—	—	—	—	35 (47)	—
HY-80	AW	L-TEC 95	106	730	91	625	24	60	—	—	—	—	—	37 (50)
	8 hr.	L-TEC 95	97	670	82	565	28	62	—	60 (81)	—	—	—	—
A387 G.22	1 hr.[b]	L-TEC U521	95	655	78	540	25	67	85 (115)	—	73 (99)	61 (83)	—	—
	8 hr.[b]	L-TEC U521	85	585	67	460	26	68	104 (141)	—	98 (133)	81 (110)	—	—
A387 G.11	1 hr.	L-TEC U515	104	715	89	615	23	61	24 (33)	—	19 (26)	17 (23)	—	—
	8 hr.	L-TEC U515	92	635	77	530	24	66	45 (61)	—	37 (50)	29 (39)	—	—
A302	2 hr.	L-TEC 44	98	675	87	600	25	64	—	—	—	—	—	21 (28)
L-TEC 0091 FLUX														
A204	1 hr.	L-TEC 40	93	640	83	570	25	68	—	—	—	—	24 (33)	—
A302	1 hr.[c]	L-TEC 44	101	695	87	600	25	67	—	44 (60)	—	—	—	—
	50 hr.[c]	L-TEC 44	85	585	72	495	28	71	—	75 (102)	—	—	—	—
T-1	AW	L-TEC 100	119	820	106	730	22	62	49 (66)	—	—	—	43 (58)	—
HY-100	AW	L-TEC 120	120	825	106	730	22	60	—	—	56 (76)	—	—	32 (43)
HY-130	AW	L-TEC 140	150	1035	135	930	15	54	49 (66)	—	—	—	—	39 (53)

Notes: [a]AWS joint design and welding parameters used — typically 500-550A DCRP, 28-30V, 16 ipm (6.8 mm/sec)
[b]Stress-relieved @ 1275°F (691°C)
[c]Plate thickness 3/4" (19 mm), cooled at 10°F/hr. after stress-relief

Figure A-94. Table of Weld Mechanical Properties for Sub Arc Welding Products (LTEC)

L-TEC FLUX/WIRE COMBINATIONS WHICH MEET AWS AND CSA SPECIFICATIONS[1][2]

AWS A5.17/ASME SFA5.17

L-TEC WIRE	L-TEC FLUX	AWS CLASSIFICATION
80	80	F6A2-EL12
	350	F6A2, F7A2-EL12
	350M	F6A2, F7A2-EL12
	231	F7AZ-EL12
81, 29	50	~~F6A2, F7A2-EM12K~~
	60	F6A2, F7A2-EM12K
	80	F6A2, F7A2-EM12K
	231	F7A2-EM12K
	350	F7A2-EM12K
	350M	F7A2-EM12K
	429	F7A2, F7P4-EM12K
	429M	F7A2-EM12K
	585	F6A2, F7A2-EM12K
	651VF	F7A6-EM12K
29S	429	F7A2-EM13K
	429M	F7A2-EM13K
	651VF	F7A6, F7P4-EM13K
36	20	F6A2, F7A2-EH14
	50	F6A2, F7A2-EH14
	60	F6A2, F7A2-EH14
	80	F6A2, F7A2-EH14
	124	F6A2, F7A2-EH14
	585	F7A2-EH14

CSA W48.6-M

L-TEC WIRE	L-TEC FLUX	CSA CLASSIFICATION
80	350	F4803-EL12
81	60	F4803-EM12K
	80	F4803-EM12K
	231	F4803-EM12K
	350	F4803-EM12K
	429	F4803-EM12K
	585	F4803-EM12K
	651VF	F4805-EM12K
36	50	F4803-EH14
	60	F4803-EH14
	80	F4803-EH14
	585	F4803-EH14

AWS A5.23/ASME SFA5.23

L-TEC WIRE	L-TEC FLUX	AWS CLASSIFICATION
WS	429	F7A2, F8A2-EW-W
	709-5	F7A2, F8A2-EW-W
ENi4	429	F8A4, F8P4-ENi4-Ni4
	709-5	F7A4, ~~F8A4-ENi4-Ni4~~
	651VF	F8A8, F8P8-ENi4-Ni4
40A	80	F7A0-EA1-A1
408	80	F7A0, F7P2-EA2-A2[3]
	124	E7A0, F7P0-EA2-A2
	709-5	F7A2, F7P4-EA2-A2[3]
	429	F8A2, F8P2-EA2-A2
40	80	F8A0, F7P0-EA3-A3[3]
	124	F8A0, F7P2-EA3-A3
	0091	F8P4-EA3-A3[3]
44	124	F8A2, F8P2-EF2-F2[3]
	709-5	F9P4-EF2-F2
95	709-5	F10A6-EM2-M2
100	709-5	F11A4-EF5-F5
	0091	F11A4-EF5-G
120	0091	F11A6-EM4-M4
U521	80	F8P0-EB3-B3[3]
	709-5	F8P0-EB3-B3[3]
U515	80	F9PZ-EB2-B2
	709-5	F9PZ-EB2-B2

Notes: [1]Additional flux/wire conformance results are available from L-TEC's extensive library of welding data. Contact your L-TEC sales office for more information.
[2]In accordance with our policy of continuing product improvement, these classifications are subject to change without notice.
[3]"P" indicates 1 hr. stress-relief. Also meets requirements after 8 hr. stress-relief.

Figure A-95. LTEC Flux/Wire Combinations - Specifications and Codes

鋼材検査証明書
INSPECTION CERTIFICATE

川崎製鉄株式会社 千葉製鉄所
KAWASAKI STEEL CORPORATION CHIBA WORKS
千葉市川崎町1番地 (〒260)
1, KAWASAKI-CHO, CHIBA, JAPAN

証明書番号 CERTIFICATE No.: PE2599
契約番号 CONTRACT No.: 6137-86860(2K1JM1324)
注文者 SHIPPER: NISSHOIWAI CORPORATION
需要家 CUSTOMER: NISSHO IWAI AMERICAN CORP., HOUSTON
品名 NAME OF ARTICLE: HOT ROLLED STEEL PLATES, ASTM A710 GRADE-A CLASS-3 MODIFIED

日付 DATE: 1985-12-26
MARKS:

製鋼番号 CHARGE No.	製品番号 PLATE No.	寸法 SIZE (mm)	員数 QUANTITY	重量 WEIGHT (kg)	試験番号 TEST No.	引張試験 TENSILE TEST 降伏点又は耐力 Y.P. or Y.S. (KSI)	引張強さ T.S. (KSI)	伸び EL.(%) GL=2IN	曲げ試験 BEND TEST 180° R=	衝撃試験 IMPACT TEST 2mm V NOTCH 10X10 -80°F FT-LBF	*: CHECK	C ×100	Si ×100	Mn ×100	P ×1000	S ×1000	Cu ×100	Ni ×100	Cr ×100	Mo ×1000	V ×1000	AL	NB	B	TENSILE TEST (THROUGH THICKNESS) RA(%) 25 MIN.
12-2018	576336A,A1	3/4"X3'X6'	2	500	Q9705	108.5	112.4	26		67.3 60.8 52.8 (60.3)	 *	6 6	30 29	152 150	8 6	3 3	110 106	92 90	33 31	401 379		55 46	33 32	16 11	T41 B35
	576334A,A1	1-1/4"X3'X6'	2	834	Q9707	111.9	116.3	24		74.5 55.0 81.0 (70.2)															T50 B57
	576335A,A1	1-3/4"X3'X6'	2	1166	Q9706	106.1	112.9	23		137.4 125.1 136.7 (133.1)															T55 B48
	576332A,A1	2-1/4"X3'X6'	2	1500	Q9693	103.3	110.2	25		81.7 102.7 88.2 (90.9)															T61 B63
	576333A,A1	2-3/4"X3'X6'	2	1834	Q9694	105.8	111.8	25		130.9 109.2 112.1 (117.4)															T62 B61
		TOTAL	10	5834 (12860	LBS)																				

AL: SOLUBLE IN ACID
Y.S. .... 0.2% OFFSET
AUSTENITE GRAIN SIZE ASTM E112 NO. 9. (12-2018)

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WE HEREBY CERTIFY THAT THE MATERIAL DESCRIBED HEREIN HAS BEEN MANUFACTURED IN ACCORDANCE WITH THE STANDARDS AND SPECIFICATIONS SPECIFIED BY YOU AND THAT IT SATISFIES THE REQUIREMENTS.

T. Sekine
検査課長
MANAGER, INSPECTION SECTION

NOTES Q.T.…Quenching Temp.焼入温度 (℃) T.T.…Tempering Temp 焼戻し温度 (℃) N.T.…Normalizing Temp 焼準温度 (℃) T…Top B…Bottom L…LONGITUDINAL C…TRANSVERSE G…GOOD
RA…Reduction of Area絞り (%) YR…Yield Ratio降伏比 (%) HB…Brinell Hardnessブリネル硬さ HR…Rockwell Hardnessロックウェル硬さ HV…Vicker's Hardnessビッカース硬さ
EV…Erichsen Valueエリクセン値 (mm) CW…Coating Weight付着量試験 MFD…MagneticFlux Density磁束密度 (T) CCV…Conical Cup Valueコニカルカップ値 (mm) CL…Core Loss鉄損値
PERM…PERMEABILITY透磁率 MA…Maximum最大 MI…Minimum最小 ※…AL, NB, TI: ×1000 B, N, O: ×10000 25C…2.5×C

頁 PAGE: 1

Figure A-96. Inspection Certificate - December 26, 1985 (Sheet 1 of 2)

鋼材検査証明書
INSPECTION CERTIFICATE

川崎製鐵株式會社 千葉製鐵所
KAWASAKI STEEL CORPORATION CHIBA WORKS
千葉市川崎町1番地 (〒260)
1, KAWASAKI-CHO, CHIBA, JAPAN

証明書番号 CERTIFICATE No.: P22599
契約番号 CONTRACT No.: 6137-86860(2K1JM1324)
注文者 SHIPPER: NISSHOIWAI CORPORATION
需要家 CUSTOMER: NISSHO IWAI AMERICAN CORP., HOUSTON
品名 NAME OF ARTICLE: HOT ROLLED STEEL PLATES, ASTM A710 GRADE-A CLASS-3 MODIFIED

日付 DATE: 1985-12-26
MARKS:

製鋼番号 CHARGE No.	製品番号 No.	寸法 SIZE mm	員数 QUANTITY	重量 WEIGHT kg	試験番号 TEST No.	引張試験 TENSILE TEST 降伏点又は耐力 Y.P. or Y.S.	引張強さ T.S.	伸び EL.(%) GL=	曲げ試験 BEND TEST 180° R=	衝撃試験 IMPACT TEST mm NOTCH °	化学成分 CHEMICAL COMPOSITION (%) C ×100	Si	Mn	P ×1000	S	Cu	Ni ×100	Cr	Mo ×1000	V	×	Ceq ×100

HEAT TREATMENT (PLATE & TEST SPECIMEN).

THICKNESS 3/4" : QUENCHING AT 1700°F x 45MINUTES
PRECIPITATION HEAT TREATED AT 1220°F x130MINUTES

THICKNESS 1-1/4" : QUENCHING AT 1700°F x 70MINUTES
PRECIPITATION HEAT TREATED AT 1166°F x150MINUTES

THICKNESS 1-3/4" : QUENCHING AT 1700°F x 95MINUTES
PRECIPITATION HEAT TREATED AT 1166°F x175MINUTES

THICKNESS 2-1/4" : QUENCHING AT 1700°F x115MINUTES
PRECIPITATION HEAT TREATED AT 1166°F x200MINUTES

THICKNESS 2-3/4" : QUENCHING AT 1700°F x135MINUTES
PRECIPITATION HEAT TREATED AT 1166°F x230MINUTES

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T. Sekine

検査課長
MANAGER, INSPECTION SECTION

NOTES Q.T.…Quenching Temp 焼入温度 (℃) T.T.…Tempering Temp. 焼戻し温度 (℃) N.T.…Normalizing Temp 焼準温度 (℃) T・Top B・Bottom L…LONGITUDINAL C…TRANSVERSE G…GOOD
RA…Reduction of Area 絞り (%) YR…Yield Ratio 降伏比 (%) HB…Brinell Hardness ブリネル硬さ HR…Rockwell Hardness ロックウェル硬さ HV・Vicker's Hardness ビッカース硬さ
EV…Erichsen Value エリクセン値 (mm) CW…Coating Weight 付着量試験 MFD…MagneticFlux Density 磁束密度 (T) CCV…Conical Cup Value コニカルカップ値 (mm) CL…Core Loss 鉄損値
PERM…PERMEABILITY 透磁率 MA…Maximum 最大 MI…Minimum 最小 ※…AL, NB, TI ×1000 B, N, O: ×10000 25C…2.5×C

頁 PAGE: 2

Figure A-96. Inspection Certificate - December 26, 1985 (Sheet 2 of 2)

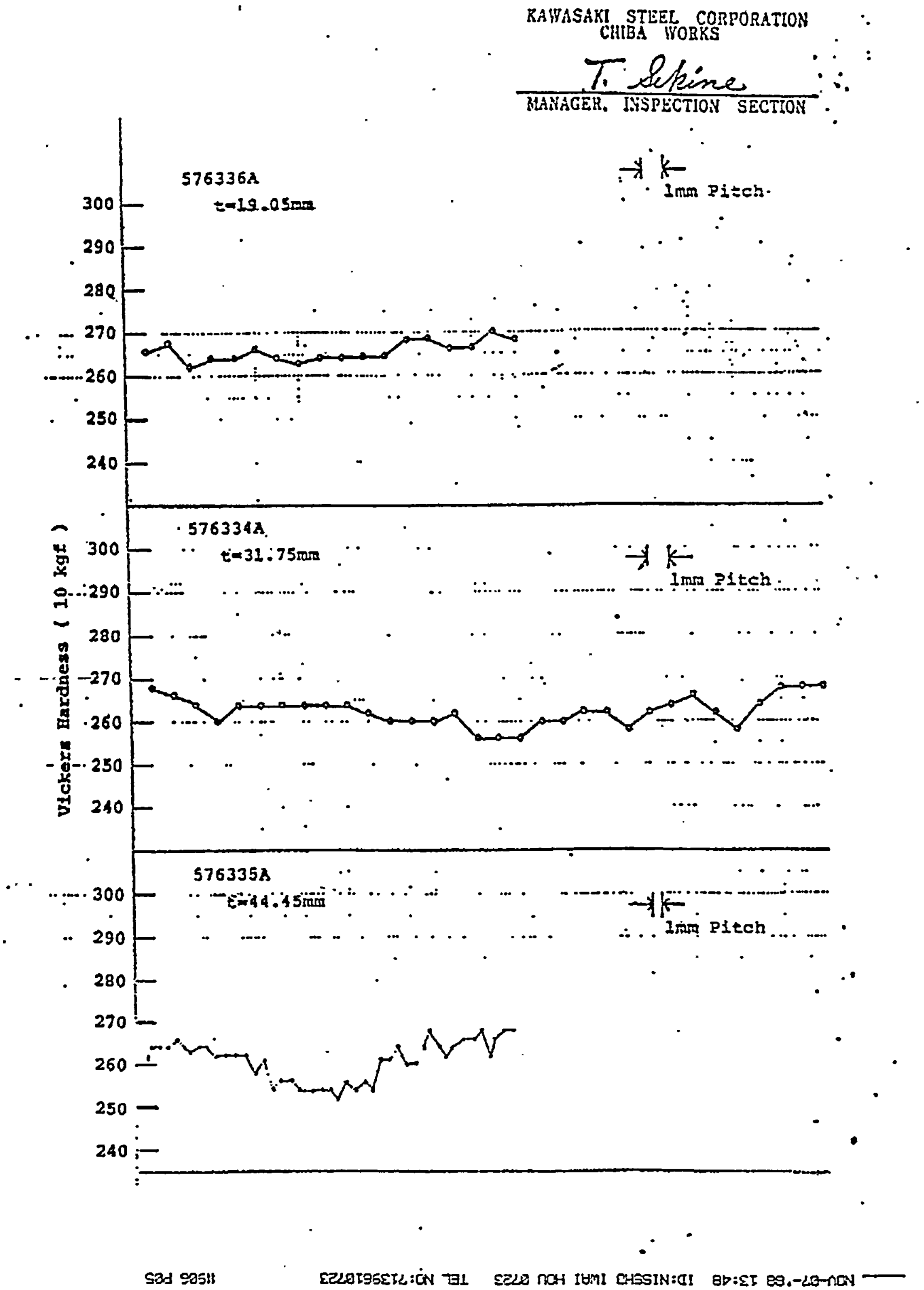

Figure A-97. Vickers Hardness for 3/4-Inch to 2-3/4-Inch Plates

KAWASAKI STEEL CORPORATION
CHIBA WORKS

T. Sekine

MANAGER, INSPECTION SECTION

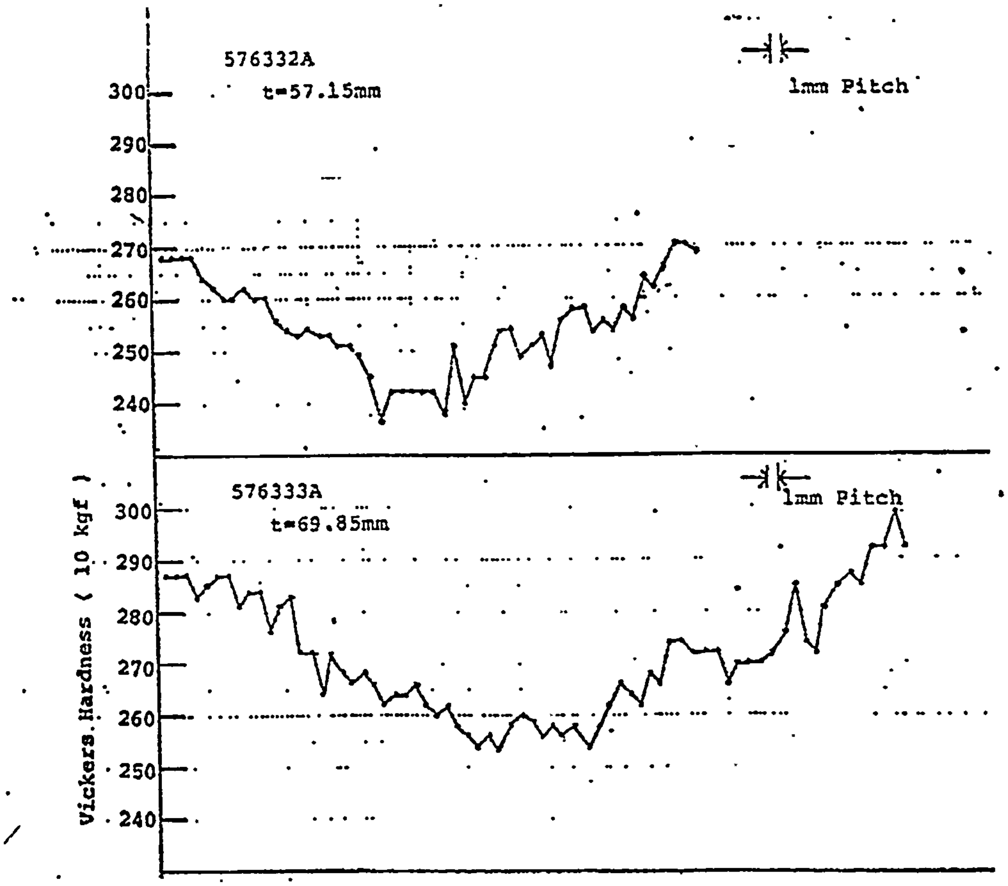

Figure A-98. Vickers Hardness for Steel Plates

4

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川崎製鉄株式会社 水島製鉄所
KAWASAKI STEEL CORPORATION MIZUSHIMA WORKS
〒712 倉敷市水島川崎通1丁目
1, MIZUSHIMA KAWASAKI DORI, KURASHIKI, JAPAN

日付 DATE :17TH FEBRUARY ,1986

証明書番号 CERTIFICATE :EA-03479
契約番号 CONTRACT No. :6137-86861 (2K1JN1324AA)
注文者 SHIPPER :NISSHOIWAI CORPORATION
需要家 BUYER :NISSHO IWAI AMERICAN CORP., HOUSTON
品名 NAME OF ARTICLE :HOT ROLLED STEEL PLATES, ASTM A710 GRADE-A CLASS-3 MODIFIED

MARKS :

CHARGE No.	ROLL No.	DIMENSIONS	QUANTITY	WEIGHT kg (LBS)	TENSILE TEST YS0.2% KSI	TENSILE STRENGTH KSI	ELONGATION % GL= 2"	IMPACT TEST 2mm V C 10x10 -080°F FT.LB	C ×100	Si ×100	Mn ×100	P ×1000	S ×1000	Cu ×100	Ni ×100	Cr ×100	Mo ×1000	V	Nb	Al	B	A	P.H.T.T.	TENSILE TEST THROUGH THICKNESS RA(%)
[illegible]-3165	A7089 A-B	3-1/4"X3'X6'	2	2166 (4775)	110.1	115.8	24	135 120 129 • 128	8	28	147	5	1	29	90	30	390		26	48	12	8	630C	T 57 B 57
	(PRODUCT)								7	27	146	5	1	27	90	29	380		25	45	11			
		TOTAL	2	2166 (4775)																				
	AJ043 A-B	3-3/4"X3'X6'	2	2500 (5512)	111.8	117.5	24	146 127 146 • 140														8	630	T 58 B 57
		TOTAL	2	2500 (5512)																				
	AJ044 A-B	4-1/4"X3'X6'	2	2836 (6252)	111.5	115.1	24	135 147 139 • 141														8	630	T 58 B 58
		TOTAL	2	2836 (6252)																				
[illegible]-3169	AN054 A-B	4-3/4"X3'X6'	2	3166 (6980)	106.8	114.1	24	63 52 72 • 62	8	32	147	5	1	27	91	28	390		26	39	13	7	635	T 36 B 37

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WE HEREBY CERTIFY THAT THE MATERIAL DESCRIBED HEREIN HAS BEEN MADE BY THE BASIC OXYGEN (L.D.) PROCESS, IN ACCORDANCE WITH THE RULES OF ASTM A710 GR.A CL.3 QUALITY STEEL, AND IS THAT WHICH HAS BEEN TESTED IN THE PRESENCE OF THE SURVEYOR TO AMERICAN BUREAU OF SHIPPING REPRESENTATIVE WITH SATISFACTORY RESULT.

S Koishi

MANAGER OF INSPECTION SECTION

Notes: QT--Quenched and Tempered 焼入焼戻し N--Normalized 焼準 Q.T.--Quenching Temp. T.T.--Tempering Temp. N.T.--Normalizing Temp. R.T.--Room Temp. RA--Reduction of Area YR--Yield Ratio HB--Brinell Hardness HRC--Rockwell Hardness HV--Vickers Hardness ET--Erichsen Value A--Austenite Grain Size No. *AL, NB, TI, ZR--×1000, B, N--×10000 ITS--Intercepting Tensile Strength

PAGE: 1

R A33E02F8ALF5LW3Q0AR39RT5S60MJ6Z50260299

Figure A-99. Inspection Certificate - February 17, 1986 (Sheet 1 of 2)

検査証明書
INSPECTION CER..IFICATE

川崎製鉄株式会社 水島製鉄所
KAWASAKI STEEL CORPORATION MIZUSHIMA WORK
〒712 倉敷市水島川崎通1丁目
1, MIZUSHIMA KAWASAKI DORI, KURASHIKI, JAPAN

CERTIFICATE No. :EA-03479
CONTRACT No. :6137-86861 (2K1JH1324AA)
SHIPPER :NISSHOIWAI CORPORATION
BUYER :NISSHO IWAI AMERICAN CORP., HOUSTON
NAME OF ARTICLE :HOT ROLLED STEEL PLATES, ASTM A710 GRADE-A CLASS-3 MODIFIED
DATE :17TH FEBRUARY ,1986
MARKS: A S B

CHARGE No.	ROLL No.	DIMENSIONS	QUANTITY	WEIGHT kg (LBS)	TENSILE TEST YS 0.2% KSI	TENSILE STRENGTH KSI	ELONGATION GL-2" %	IMPACT TEST 2mm V C 10×10 -080°F FT.LB AVE	C ×100	Si ×100	Mn ×100	P ×1000	S ×1000	Cu ×100	Ni ×100	Cr ×100	Mo ×1000	V ×1000	NB	AL	B	TENSILE TEST (THROUGH THICKNESS) RA(%) / P.H.T.T.
		TOTAL	2	3166 (6980)																		
T-3169	AN055 A-B	5-1/4"X3'X6'	2	3502 (7721)	107.0	114.9	24	77 66 56 67	8	32	147	5		127	91	28	390		26	59	13	7 630C T 38 B 37
									(PRODUCT)													
									7	30	146	5	1	126	90	29	380		24	57	11	

*****PLATE QUENCHED AT 1700°F
PLATE PRECIPITATION HEAT TREATED AT 1166°F × 225MIN(3-1/4")
1166°F × 200MIN(3-3/4")
1166°F × 270MIN(4-1/4")
1175°F × 320MIN(4-3/4")
1166°F × 340MIN(5-1/4")

P.H.T.T. PRECIPITATION HEAT TREATMENT TEMP.

			QUANTITY	WEIGHT kg (LBS)
		TOTAL	2	3502 (7721)
		G-TOTAL	10	14170 (31240)

SURVEYOR TO AMERICAN BUREAU OF SHIPPING

AMERICAN BUREAU OF SHIPPING TOKYO

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S. Koishi
MANAGER OF INSPECTION SECTION

Note: QT--Quenched and Tempered; N--Normalized; Q.T.--Quenching Temp.; T.T.--Tempering Temp.; N.T.--Normalizing Temp.; R.T.--Room Temp.; RA--Reduction of Area; YR--Yield Ratio; HB--Brinell Hardness; HRB/HRC--Rockwell Hardness; HV--Vicker's Hardness; EV--Impact Value; A--Austenite Grain Size No.; ●AL, NB, TI, ZR--×1000, B, N--×10000; ITS--Interlocking Tensile Strength

PAGE: 2

R A33EQ2F9AL73LM590AR59R73S60NJ6Z30Z6AZ29

Figure A-99. Inspection Certificate - February 17, 1986 (Sheet 2 of 2)

APPENDIX B

WELDING EQUIPMENT USED
FOR WELD TEST ASSEMBLIES

Linde 450 Pulse, Constant Potential Power Supply (MIG Welding)

L-Tee Digimie Deluxe Wire Feeder - Using a Microprocessor with Digital Logic

MT-400 (L-Tec) Light Weight Air Cooled Torch for 250 Amps 100 percent Duty Cycle with Argon Mixture and 400 Amps 100 percent duty Cycle with $C0_2$

L-Tee VI-1200 Submerged Arc Welding Power Supply for up to 1200 Amps

L-Tee uNM-8 and UWM-9 Single Sub-Arc Arc Assembly for AC or DC Welding

L-Tee Busbar and Nozzle Assemblies for Straight Nozzle, Curved Nozzle and Deep Groove

UEC-8 (L-Tee) Basic Submerged Arc Welding Control for AC or DC, Constant Current or Constant Voltage

Linde 650 CV/CC Power Supply for MIG Spray Arc Flux Core and Shielded Metal Arc (700 Amp)

Miller Power Supplies:

- Dimension 400 for 400 Amp CD/CC for SMAW, GMAW and Subarc
- Thunderbolt 225 for 225 amp CC SMAW
- Square base 1000 - Constant Voltage 1000 Amp for Subarc
- Econotwin for 150 Amp Constant Current SMAW Welding

APPENDIX c

SEPTEMBER 1987 “WELDING JOURNAL” PAPER ENTITLED
“THE BENEFITS OF NEW HIGH STRENGTH LOW ALLOY (HSLA) STEELS"
DELIVERED TO THE 1987 AWS CONVENTION IN CHICAGO BY T.L. ANDERSON

The Benefits of New High-Strength Low-Alloy (HSLA) Steels

A precipitation-hardened steel may be the best answer to the high cost of welding, because less preheat maybe used

BY T. L ANDERSON, J. A. HYAIT AND J. C. WEST

Welding of high strength low-alloy (HSLA) steels often requires extensive preheat, specialized welding procedures, and sometimes heat treatment to avoid cracking problems, These cracking problems are often caused by the high carbon and alloy content necessary to attain high-strength levels. When a precipitation-hardened steel is used, these problems can be reduced significantly, along with welding and repair costs. [n today's highly competitive environment, costs must be kept to a minimum in order to assure survival. A precipitation-hardened steel may be the best answer to the high cost of welding high-strength steels-not only in shipbuilding and offshore structures, but in other fabricated steel products as well.

Introduction

The Navy is cost conscious and is trying to reduce cost whenever possible. In 1982, NAVSEA'S Material Fabrication Improvement goals were established for fiscal years 1983 through 1990. The prime goal was to "reduce shipbuilding costs through improvement of welding processes, materials, technologies, procedures, and techniques, while simultaneously improving overall quality." Most of the high-strength steels used in Navy construction, particularly HY-80 and HY-100, attain their strength levels from a quench-and-temper heat treatment. The welding of these steels requires the use of sustained preheat, controlled interpass temperatures and heat input limitations. Strict adherence to these requirements is mandatory to avoid cracking in hydrogen-sensitive steels and to assure the desired mechanical properties. Unfortunately, these requirements increase cost considerably.

In order to reduce cost, an alternative steel with similar properties was sought. The A710 Grade A steel used in the offshore industry was chosen for testing. it has the ability to attain 80,000 psi *(551.7* MPa) yield strength and has the necessary toughness. Its ASTM ch":.tlL. 'composition and minimum mechanical properties arc II!iLQ~ in Table 1. The A710 steel obtains its strength from precipitation hardening, and because of a low carbon content (0.07 max.), it is much less sensitive to hydrogen-induced cracking. The material was tested by the Navy and certified for use through thicknesses of 11A in. (32 mm) for structural applications. Testing continued on thicknesses through 2 in, (51 mm).

T.L. ANDERSON, J.A. HYATT and J.C.WEST are with Bethlehem Steel Corporation, Beaumont, Tex.

BethIehem's Experience

In 1981, Bethlehem required a high-strength steel with excellent toughness in a new design of the critical column leg-to-mat deck connection of an offshore oil rig – Figs. 1 and 2. A combined effort with Armco personnel led to specifying Armco's NI-COP, which is made to ASTM A710 for general applications and A736 for pressure vessel use. The A736 specification was chosen because of its stricter testing requirements. Plates of 2%,3 and 5 % in. (70,76 and 140 mm) thick were purchased in the quenched-only concfition. The lower yield of the quenched-only material permitted easier rolling of the sections to the required diameter. The subassembly was welded and then precipitation hardened to attain the desired strength level. Yield points of 83,200 psi (573.7 MPa) for the 2?4 in., 77,100 psi (531.7 MPa) for the 3 in., and 70,700 psi (487.5 MPa) for the 5Yz in. material were reached. Charpy impact values in the HAZ were outstanding, averaging almost 200 ft-lb (271 J), including some no-breaks at 264 ft-lb (358]) and at 40"F (-400 C).

Request for Funds

[n 1983, Bethlehem made a proposal to the SP-7 welding panel of the ship production committee, Society of Naval Architects and Marine Engineers (SNAME), for a four-phase

Table I—Chemical Composition and Mechanical Properties MM-A71O Grade A Class 3

Chemical Composition (%)	
Carbon	0.07
Manganese	0.40-0.70
Phosphorus	0.025
Sulfur	0.025
Silicon	0.40
Nickel	0.70-1.00
Chromium	0.6.0-0.s0
Molybdenum	0.15-0.25
Copper	1.00-1.30
Columbum	0.02
Mechanical Properties	
Yield strength	75 ksi through 2 in. 65 ksi over 2 in.
Tensile strength	85 ksi through 2 in. 75 ksi over 2 in.
% Elongation	20
Notch toughness	50 ft-lb @ -800F

* Reprinted from November, 1987 issue of The Welding Journal

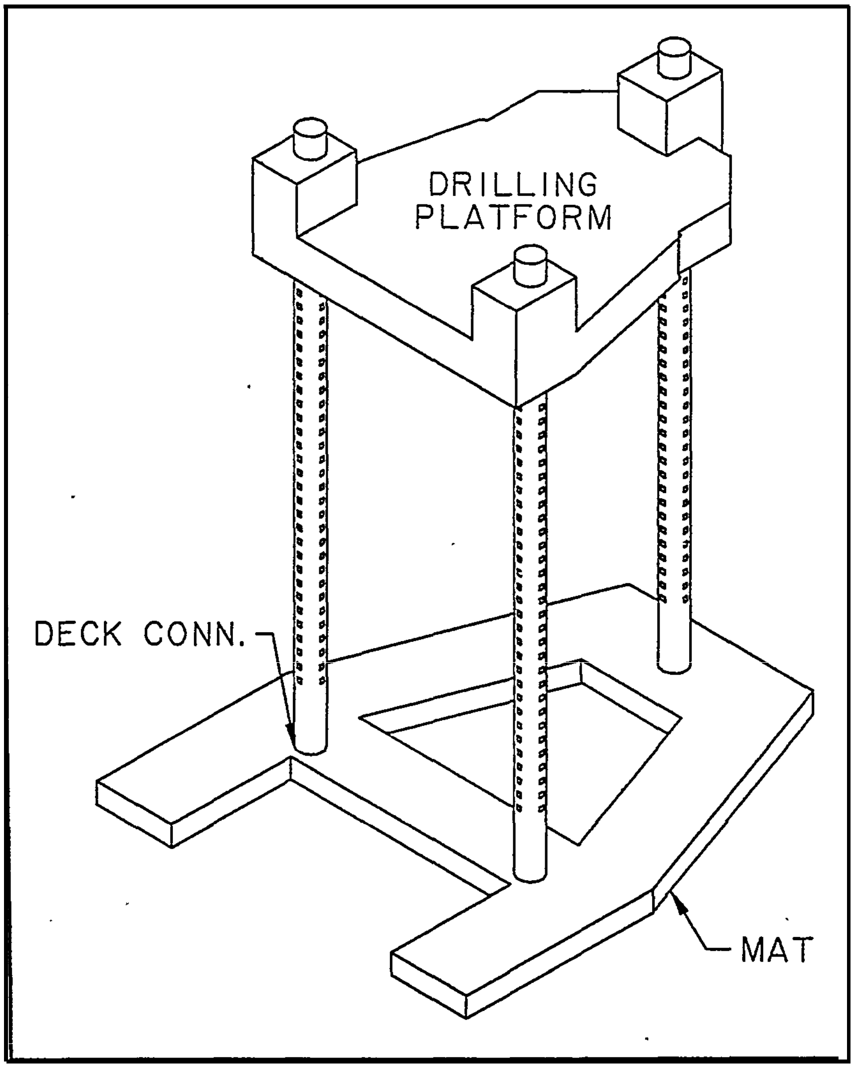

Fig. 1—250-ft water depth jack-up rig

project to evaluate the benefits of A710 in thicknesses through 6 in. (152 mm). The. project was approved in February 1984, with funding administered by the Maritime Administration. The goals of the project were to successfully weld ASTM A710 without sustained preheat and without heat input limitations. Strength levels for the first two phases were targeted at 80,000 psi (551.7 MPa) yield through 3 in. (76 mm), 75,CMI0 psi (517.2 MPa) yield through 5 in. (127 mm), and 70,000 psi (482.7 MPa) yield through 6 in. (152 mm). In the last two phases of the project, a modified version of the A710 would be tested with strength levels targeted for 100,000 psi (689.6 MPa) yield through 3 in., 90,000 psi (620.6 MPa) yield through 5 in., and 85,000 psi (586.2 MPa) yield through 6 in. This paper will present the work and results of the first two completed phases.

Progress Report

Work started in August 1984 on the first phase of the project. Phase 1 consisted of plate thicknesses of 2U, 2% and 3 in. (57, 70 and 76 mm). Welding processes used included SMAW, pulsed GMAW, SAW, and narrow gap SAW, with emphasis on the submerged arc processes. The 2?4 -in. material was tested first since it was in the quenched-only condition, having the following chemistry

C	Mn	P	S	Si	Cr	Ni	Mo	Cu	Cb
0.03	0.50	0.010	0.005	0.21	0.78	0.91	0.20	1.23	0.037

Six test pieces of the 2%-in. plate were precipitation hardened at temperatures ranging from 1000° to 1125°F (538° to 607"C) for 1 h per in. thickness (165 min). Tensile and impact tests were conducted to determine the optimum precipitation-hardening temperature. The tensile test results (Fig. 3) showed that at a 1000°F precipitation hardening temperature the highest strength levels of the temperatures tested were attained. The impact tests (Fig. 4) were conducted at –80"F (-62"C) and did not lead to a definite conclusion on an optimum preapitation-hardening temperature. Data from the manufacturer were consulted and it was deaded that a precipitation-hardening temperature of 105OOF (566"C) would produce the best overall results.

The first set of test plates were welded in the quenched-only condition at various heat inputs and then preapitation hardened. Another set of test plates wc e precipitation hardened and then welded at the same heat mpuw. Mechanical tests conducted on the test plates included a weld metal tensile test, reduced section tensile tests, Charpy V-notch impact tests, side bend tests, and a Rockwell hardness test on a cross-section.

The results, compared by heat inputs in Table 2, exhibit no significant difference in weld metal strength. The reduced section tensile tests did not reveal a distinction in strength levels. The impact test results did exhibit a substantial difference in toughness. Test plates that were precipitation hardened and then welded appear to have consistently higher impact values.

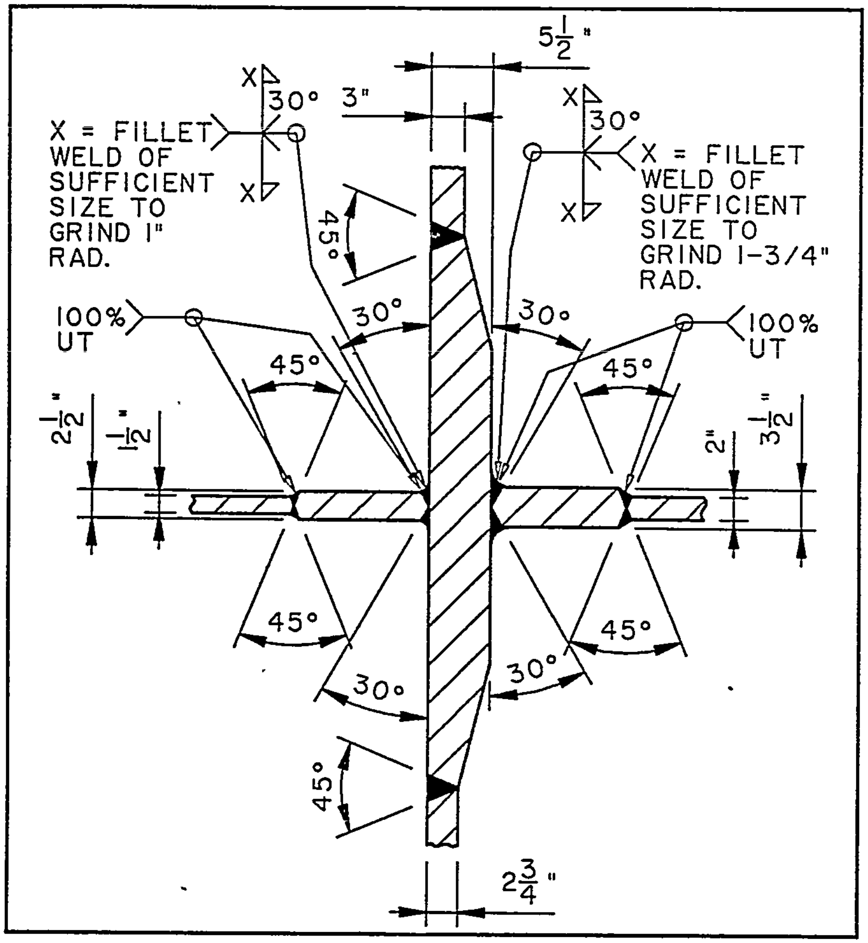

Fig. 2—New design mat connection

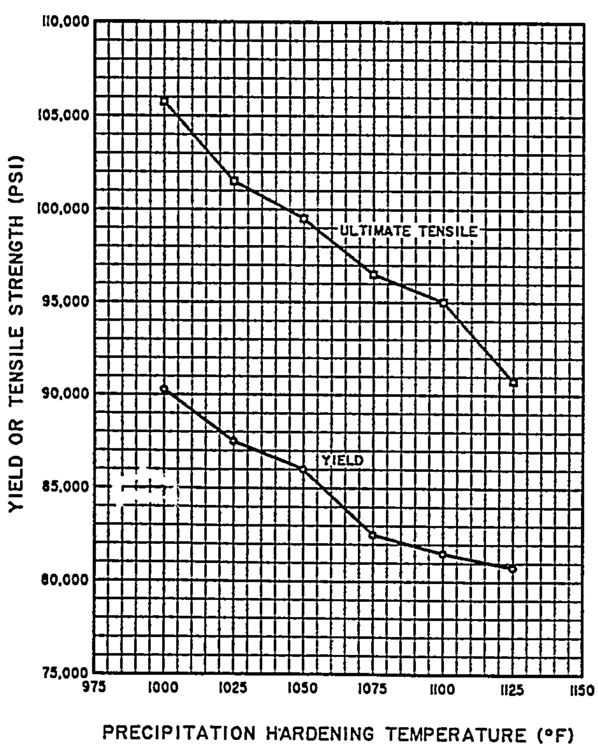

Fig. 3—Precipitation-hardening temperatures vs. yield and tensile strengths

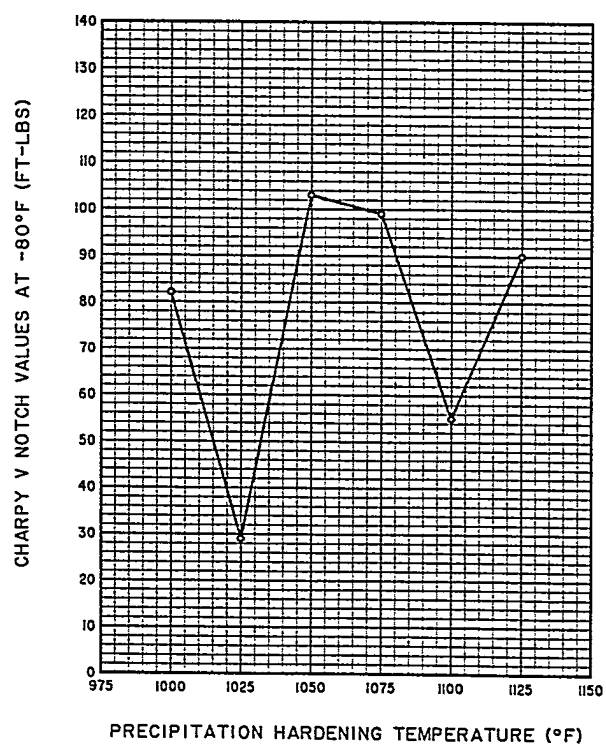

Fig. 4—Precipitation-hardening temperatures vs. impact values

Table 2—Submerged Arc Welded 2¾-in. Test Plate Comparison

Condition of plates	QO[a]	PH[b]	QO	PH	QO	PH	QO	PH	QO	PH
Heat input (J/in.)	200,000	200,000	150,000	150,000	125,000	125,000	100,000	100,000	75,000	75,000
Weld metal (psi)										
Yield	87,165	84,766	91,134	88,072	87,868	89,787	93,167	97,634	94,368	94,752
Tensile	107,074	105,798	106,983	107,649	107,688	106,956	107,867	109,461	105,885	106,011
Reduced section (psi)										
Yield	—	90,370	—	89,164	—	93,023	—	95,852	—	89,914
Tensile	102,861	102,262	108,311	105,896	108,950	102,844	107,955	106,353	100,820	103,279
Charpy V-notch (ft-lb) at	−80°F	−40°F	−40°F	−40°F	−40°F	−40°F	−40°F	−40°F	−40°F	−40°F
Weld	9	40	31	78	28	86	43	76	29	74
1 mm	30	88	53	74	52	76	77	50	46	52
3 mm	41	95	48	64	48	64	38	80	33	72
5 mm	22	56	43	102	43	94	32	103	29	91
Rockwell (B scale)										
Weld metal	98.2	98.6	99.6	99.0	97.8	98.4	99.3	98.5	98.7	97.6
HAZ	—	94.3	—	93.3	—	97.2	—	93.8	—	96.3
Base metal	96.6	100.0	100.1	100.0	98.1	93.7	97.2	99.7	99.0	97.3
Side bends	S	S	S	S	S	S	S	S	S	S

(a) QO plates precipitation hardened after welding.
(b) PH plates precipitation hardened before welding.

Table 3—3-in. Test Plate Results

Welding process	narrow gap
Heat input (J/in.)	72,600
Weld metal (psi)	
Yield	93,359
Tensile	105,791
Reduced section (psi)	
Yield	93,961
Tensile	104,646
Charpy values (ft-lb)	−40°F
Weld	61
1 mm	112
3 mm	73
5 mm	67
Side bends	satisfactory
Rockwell hardness (B scale)	
Weld	97.9
HAZ	96.8
Base metal	94.1

Table 4—2¾-in. Test Plate Results

Welding process	pulsed GMAW
Heat input (J/in.)	60,800
Weld metal (psi)	
Yield	88,721
Tensile	101,604
Reduced section (psi)	
Yield	92,433
Tensile	100,134
Charpy values (ft-lb)	−40°F
Weld	79
1 mm	109
3 mm	93
5 mm	69
Side bends	4 satisfactory 4 unsatisfactory
Rockwell hardness (B scale)	
Weld	97.8
HAZ	—
Base metal	94.0

Table 5—2¼-in. Test Plate Results

Welding process	SAW	Pulsed GMAW	SMAW (flat)	SMAW (vertical)
Heat input (J/in.)	133,000	59,000	31,200	41,200
Weld metal (psi)				
Yield	93,237	88,801	broke outside gauge marks	89,582
Tensile	107,956	91,317		100,905
Reduced section (psi)				
Yield	87,719	82,159	77,474	90,555
Ten[illegible]	96,455	94,147	94,700	98,517
Charp[illegible] (ft-lb)				
Weld	23	67	21	15
1 mm	63	98	155	136
3 mm	103	145	129	151
5 mm	103	142	192	117
Side bends	satisfactory	3 satisfactory 1 unsatisfactory	2 satisfactory 2 unsatisfactory	unsatisfactory
Rockwell hardness (B scale)				
Weld	98.2	95.8	106.8	not conducted
HAZ	—	—	—	
Base metal	96.3	92.9	93.3	

As shown in Fig. 5, the weld metal strength tends to decrease as the heat input increases, but remains above the 80,000-psi yield level. The graphs in Fig. 6 show no apparent relationship between heat input and toughness within the ranges studied.

An additional 3-in. plate was welded with the narrow gap submerged arc process. The narrow gap joint was obtained by using a backing bar and spacing the square edges of the plate 0.75 in. (19 mm) apart. A split layer technique was used to avoid problems with slag locking into the sidewalls. The favorable results are shown in Table 3.

One 2¾-in. test plate was welded with the pulsed gas metal arc process. This plate was welded in the flat position with the aid of a mechanical tractor unit. The heat input on this test plate was calculated to be approximately 60,800 J/in. (2394 J/mm). The test results are listed in Table 4.

The 2¼-in. test material was also in the quenched-only condition. Four test plates (Table 5) were welded, precipitation hardened and tested. One test plate was welded using the SAW process, one with pulsed GMAW, and two using SMAW.

In the second phase, test plates 4, 4½, 5 and 6 in. (102, 114, 127 and 152 mm) were tested. All these plates were obtained in the precipitation-hardened condition. Welding processes used included SMAW, GMAW, SAW, and narrow gap SAW. Emphasis was given to the submerged arc processes because of the thickness.

The two 4-in. plates were welded first, one with pulsed GMAW in the vertical position and the other with SAW—Table 6. The reduced section yield results show averages above the 80,000-psi level. The base metal impact values are similar despite the large difference in heat input.

The 4½-in. plates (Table 7) were welded and tested using narrow gap SAW, vertical SMAW, and vertical pulsed GMAW. The reduced section tensile results are once again alike, along with base metal impact values.

Two 5-in. test plates were welded with SAW and narrow gap SAW. The reduced section results, given in Table 8, are very close to each other. The impact results in the base metal are again similar, while the weld metal results differ due to the difference in heat inputs.

The two 6-in. test plates were also welded with SAW and narrow gap SAW, and these test results are displayed in Table 9. The reduced section tensile tests both exceeded the 80,000-psi yield level. Once again, the base metal impacts are comparable. The 5-mm values would have been more comparable if not for one unusually low specimen value which decreased the overall average.

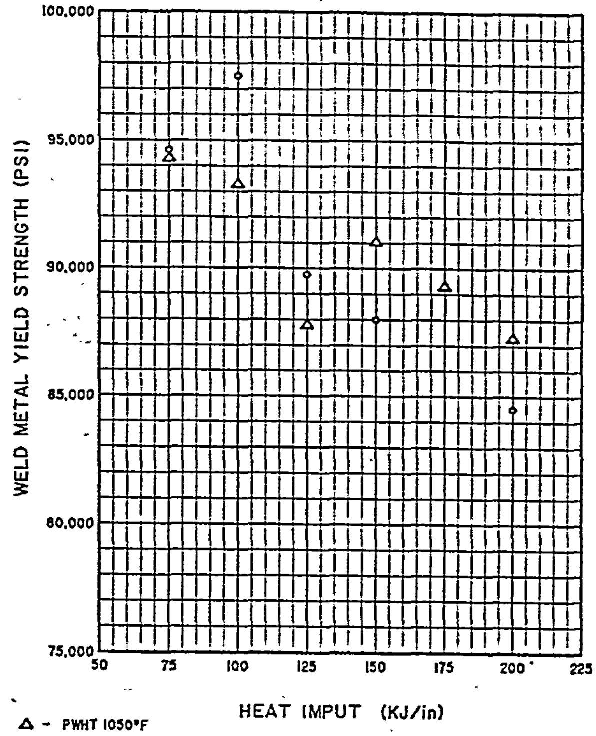

Fig. 5—Weld strength vs. heat input

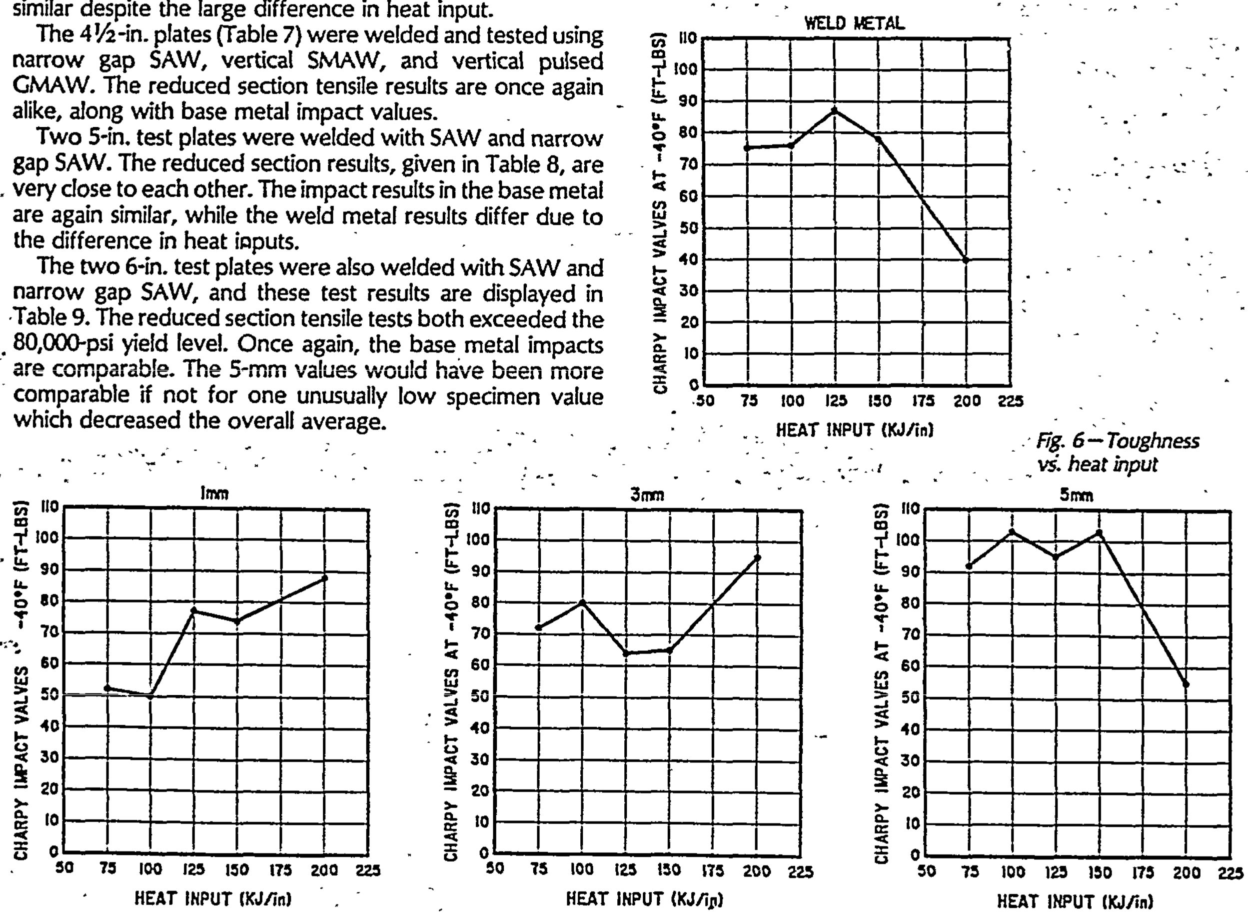

Fig. 6—Toughness vs. heat input

Table 6—4-in. Test Plate Results

Welding process	SAW	GMAW
Heat input (J/in.)	191,000	35,000
Weld metal (psi)		
Yield	76,687	99,396
Tensile	105,879	108,454
Reduced section (psi)		
Yield	83,995	87,012
Tensile	97,974	100,801
Charpy values (ft-lb)		
Weld	11.5	84
1 mm	86	83
5 mm	94	82
Side bends	satisfactory	3 satisfactory 1 unsatisfactory

Table 7—4½-in. Test Plate Results

Welding process	narrow gap SAW	SMAW (vertical)	GMAW (vertical)
Heat input (J/in.)	73,600	52,000	35,000
Weld metal (psi)			
Yield	96,741	93,611	105,633
Tensile	105,213	104,668	111,371
Reduced section (psi)			
Yield	78,005	79,664	76,529
Tensile	89,816	89,369	87,898
Charpy values (ft-lb)			
Weld	71	33	59
1 mm	139	112	160
5 mm	134	117	129
Side bends	satisfactory	satisfactory	2 satisfactory 2 unsatisfactory

Table 8—5-in. Test Plate Results

Welding process	SAW	narrow gap SAW
Heat input (J/in.)	139,170	72,200
Weld metal (psi)		
Yield	78,222	96,605
Tensile	104,054	104,992
Reduced section (psi)		
Yield	78,448	79,460
Tensile	86,016	89,996
Charpy values (ft-lb)	−40°F	−40°F
Weld	37	87
1 mm	132	135
5 mm	131	172
Side bends	unsatisfactory	satisfactory

Table 9—6-in. Test Plate Results

Welding process	narrow gap SAW	SAW
Heat input (J/in.)	74,700	147,334
Weld metal (psi)		
Yield	93,942	82,788
Tensile	105,133	90,035
Reduced section (psi)		
Yield	84,650	80,955
Tensile	92,743	94,445
Charpy values (ft-lb)		
Weld	51	64
1 mm	71	77
5 mm	89	59
Side bends	satisfactory	unsatisfactory

Conclusion

The weldability of the A710 steel is excellent. In all test plates welded with only drying preheat, there was no base-metal-related cracking. This is directly related to the low carbon content and carbon equivalent. Even though the preheat used in these tests was minimal, preheat may be required during construction due to conditions of excessive restraint. The precipitation-hardening chemistry allows the higher heat input processes to be used without restriction. The only restrictions on heat input appear to be process limitations, joint geometry, and good welding practices.

The cost of A710 is lower when compared with HY-80, but is somewhat higher than other high-strength steels used in other industries. The lower preheat requirement and excellent weldability of this steel will probably lower production costs and cracking-related repairs enough to overcome the slight price difference.

When A710 is substituted for a lower strength steel, as the Navy is considering, costs will be decreased in several areas. The increased strength level allows the use of thinner plates in many applications. This would reduce the weight of the unit, which in the case of ships or offshore drilling vessels increases the payload. The amount of welding consumables needed would be reduced, as would the man-hours required to weld it. The thinner material also translates into longer plates from the mill, which means fewer joints required per unit.

Table 10-Chemical Composition and Mechanical Properties of A71O with Modified Chemistry

Chemical Composition (%)	
Carbon	0.07
Manganese	1.20-1.70
Phosphorus	0.025
Sulfur	0.025
Siicon	0.40
Nickel	0.70-1.00
Chromium	0.10-0.50
Molybdenum	0.20-0.s0
Copper	1.00-1.35
Columbum	0.02
	0.015-0.06s
Boron	trace
Mechanical Properties	
Yield	100,CKXI psi
Tensile	125,000 psi
% Elongation	20
Notch Toughness	50 ft-lb @ -80°F

Future Plans

Bethlehem has had to reduce the extent of Phase 3 because of funding reductions in the federal budget. The goal of Phase 3 is to weld the A710, using the modified chemistry shown in Table 10, with a minimum 100 ksi (689 MPa) yield through 3 in., with only minimum preheat and without heat input limitations.

The material has been procured from a Japanese source. The delivered price was 52 centsAb for thicknesses through 2⅞ in. and 58 centwlb for thicknesses of 3M in. through 5¾ in.

Welding processes scheduled to be tested include pulsed GMAW, SMAW, SAW, narrow gap SAW, and consumable guide ESW. Work is progressing on this phase, and initial results indicate that we will attain our goal.

APPENDIX D

M4Y 1987 “JOURNAL OF SHIP PRODUCTION” PAPER ENTITLED
“THE BENEFITS OF A MODIFIED-CHEMISTRY LOW ALLOY STEEL”
PRESENTED TO THE SHIP PRODUCTION SYKPOSIUM AT
WILLIAMSBURG, VA., AUGUST 1986 BY J. C. WEST

The Benefits of a Modified-Chemistry, High-Strength, Low-Alloy Steel

John C. West[1]

Steels with 50 ksi and up yield points usually acquire their strength from some form of heat treatment. hlost of these steels, 11/2 in. thick and up, must be welded using sustained preheat and controlled interpass temperatures, plus controlled welding heat input of approximately 50 to 60 kJ/in. These two items can add as much as 50 percent to the cost of submerged-arc welding, and increases of up to 30 percent are common for manual welding when compared with lower-strength steels previously used. To reduce costs, a quenched and precipitation-hardened steel, ASTM A710 Grade A Class 3, with a high degree of weldability, was tested. This steel, which can be welded without sustained preheat and almost unlimited heat input, has been extensively tested in thicknesses from 2% through 6 in. Although this steel costs more than the usual quenched-and-tempered plates at these strength levels, reductions of 40 to 75 percent in welding labor costs are probable. In additior, sizeable material savings should be realized when these items are used in place of HY-80 and HY. 40.

Introduction

In 1982 Two significant events in ship production occurred, almost simultaneously.

In the first event, the goal of the Naval Ship Engineering Center's (NAVSEA) material fabrication improvement MFI) program plan for FY 1983-FY 1990 was established. Its aim was to "reduce shipbuilding costs through improvement of welding processes, materials, technologies, procedures, and techniques; while simultaneously improving quality."

NAVSEA had found that over 11 percent of the construction man-hours needed to build a ship were devoted to structural welding, which was dominated by the manual process. Sustained preheat and interpass temperature controls needed when welding HY-80 and HY-1OO cost approximately $1.5 million for a fair-sized vessel, and larger units up to $15 million, as outlined by R. R. Irving in his paper "A Cost Effective Replacement for HY-80?" in the May 16, 1986 issue of Iron Age [1]?

In the second event, we at Beaumont were deeply involved in worldwide offshore drilling and exploration for oil and gas. Our purpose was to design,-build, and continue to improve in our production of top-quality, economical drilling rigs.

Bethlehem-Beaumont has, over the years, designed many offshore drilling and production units 84 jack-ups, several semisubmersibles, and production platforms, which have been built at Beaumon$ Singapore Sparrows Point Durban, South Africa and in the Peoples Republic of China.

Technical development

The jack-up rigs are classified by rated water depth—150 ft, 80 ft, 175 ft, 200 ft, 250 ft, etc. The model (Fig. 1) has three legs or columns which are pierced with holes when the unit is built to permit entry of the jacking and fixed pins. Surrounding each column is an area of the platform known as the jack house. This is where lifting and lowering of the mat is controlled.

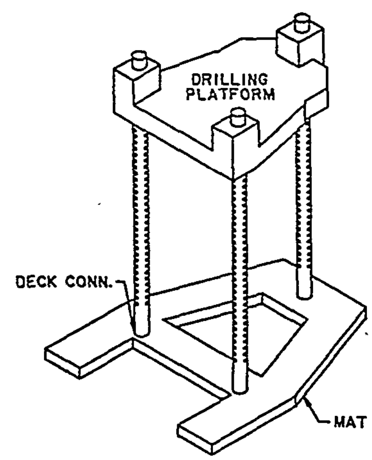

Fig. 1 250-ft water depth jack-up

The mat, resting on the seafloor, is penetrated by the three columns. This mat deck-to-column connection is shown on the attached "old design: Fig. 2. The section view shows the ABS EH36 column (21/z in.) and the ABS EH36 wrapper plate (13/4 in.) tied to it with an upper and lower 21/Z-in.-by-3-in. fillet weld made by sub-arc in the fabricating shop. Note the gap between the wrapper plate and column between the fillet welds this allows the plate to move, or "flex." The drawing callouts are for 100 percent ultrasonic test inspection. The weld at the deck is made with E8018C-3 electrodes and ground to a 7/8-in. radius on the handling ways.

Initially, the wrapper plate was used for easier assembly of this vital joint. It could be installed as a coaming on the deck and columns passed through it and tied in by the two fillet welds. Later on this was changed as previously outlined.

The original joint was designed to flex or "breathe" as the loads were transmitted between the column and the deck. Failure of this joint can be catastrophic and, if left unattended, serious trouble will occur. On some earlier units, the

'Bethlehem Steel Corporation, Beaumont Yard, Beaumont, Texas.
Numbers in brackets designate References at end of paper.
Presented at the Ship Reduction Symposium, Williamsburg, Virginia, August 27-29, 1986.

* reprinted from Proceedings of the National Shipbuilding Research Program Symposium, Williamsburg, Virginia, August, 1986.

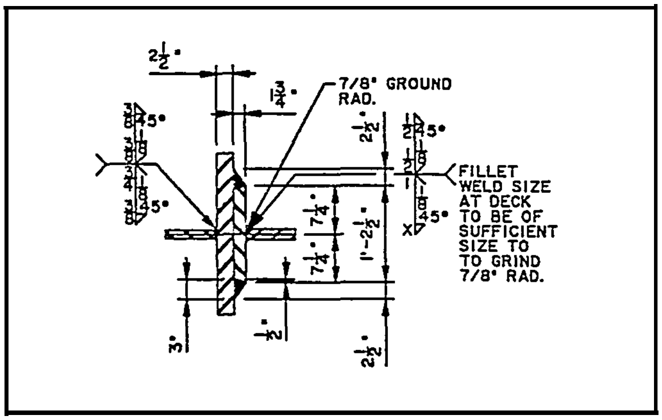

fig. 2 "Old' design mat connection

wrapper plate cracked through behind the upper part of the deck to wrapper plate weld. Then the wrapper plate had to be replaced, under difficult conditions, in remote parts of the world such as Angola, Brazil, Egypt, Gabon, and Southeast Asia. On many occasions, due to local limitations, workers had to be sent from the United States or Western Europe.

The vast costs incurred to our customers, plus the drop in their "day rate" while laid up for repairs, plus American Bureau of Shipping (ABS) insistence, led us to work toward a new design for this joint.

The new design

Figure 3 shows a sketch of the new design, evolved at Beaumont, which led to a search for a steel 5 1/2 in. thick with a 65-kai yield point and a high toughness level.

Discussions between Armco and Bethlehem personnel led to the selection of their W-COP" for this application.

"NI-COP" was made to ASTM A71O for general applications and ASTM A736 for pressure vessel use. A736 was chosen for our application because of its stricter testing requirements. At that time, Armco had not produced anything thicker than 3 1/4 in. and were not sure that 5 1/2 in. could be produced, rolled, and welded to attain a 65-ksi yield point.

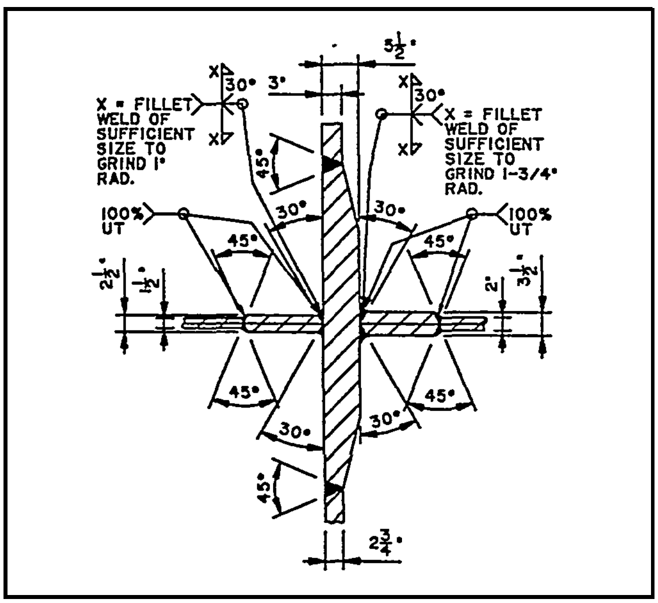

fig. 3 "New" design mat connection

After consultation with various metallurgical engineers, it was decided to purchase the 2314-in. and 51/2-in. material in the quenched condition only. We would roll the 23/4-in. and 3-in. at Beaumont and subcontract rolling the 51/z-in. to Wyatt Industries in Houston. Wyatt's -rolling preheat of the 5%+. plate, because of job limitations, was limited to 500"F. We would weld up the subassembly, including the diaphragm, a 15-in. section of deck plate, and the lower portion of the column tube. We would then precipitation-harden the subassembly in our furnace. The section view of Fig. 3 shows this in detail.

We accomplished this with the three column-to-mat 45-ton stub subassemblies for the fmt rig being welded and heat-treated by March 8, 1982. Succeeding subassemblies were also done in this fashion at a later date. No one had ever done this in the past.

Average yield points attained were 83.2 WI for 2314-in., 77.1 kai for the 3 in., and 70.7 ksi for the 51/2 in. TheSe are recorded on our ABS-approved 'Welding Procedures 335 and 336" dated April 12, 1982. V-notch values were excellent and thera was no adverse heat-affected zone (HAZ) degradation.

The reader is, perhaps, familiar with this material as it is also known as HSLA-80 and being used on U.S. Navy ships. The July 1985 issue of Welding Journal contains an excellent paper, "An Improved High Yield Strength Steel for Shipbuilding" [2] authored by L. G. Kvidahl of Ingalls Shipbuilding. In the paper, test results are extensively detailed; and when compared with HY-80, a better product for less money results.

The new chemistry

These aforementioned findings were fed back to Armco to assist them in their product development work. On March 28,1983, we were advised that Armco had developed a modified chemistry for A71O that could attain a guaranteed minimum yield point of 100 ksi through 2 in.; and that the standard chemistry could now be sold at an 80 yield point minimum through 1 1/4% in. We were informed that Armco was planning to sell this to the U.S. Navy in place of HY-80. Verbal quotes at that time were 58 cents/lb for the standard chemistry and 63 cents/lb for the modified.

In late September/early October of 1983, it was learned that Armco would close its Houston works and that the above products would be no more. At that time we received some of Armco's development data and documents that further endorsed the belief that this product really had the potential to replace HY-1OO.

Request for MarAd study funds

The preceding events led us to propose to the 5P-7 Welding Panel of SNAME on November 10, 1983, the study YEvaluate the Benefits of Higher-Strength HSLA Steels." On February 13,1984, we were advised that 5P-7 had approved the study and a formal contract for $95000 for the f~t-year funds would be forthcc-tink fkom the Maritime Administration (MarAd).

Work commenced in August 1984 to accomplish the goals listed in Table 1, without using sustained preheat and limited heat input.

Accomplishments

In May 1986, we met our goals and completed Phases 1 and 2 within budget.

The welding processes used were manual, gas metal-arc with pulse, and submerged arc (single, dual arc, and narrow gap). Heat inputs varied from 50 kJ/in. to 200 kJ/in. Some plates were welded in the quenched-only condition, and precipitation-hardened after welding others vice veraa. Test results obtained in 3-in. material show a minimum yield of 84.7 ksi welded at 200 kJ/in. with dual arc to 94.7 lcA welded at 75 kJ/in. with the same process. Charpy V-notch values were well above the ABS values for EQ56 plates.

Table 2 gives test results of Phases 1 and 2. Note that results for welding before and after precipitation hardening are listed. Beaumont haa done this in production runs as we have a 17 x 17 x 85-ft car bottom furnace. We do not recommend this practice for overall general use. The soak times and temperatures plus cooling rates are exacting and critical. Undivided attention, accuracy, and constant monitoring are required to be successful. There is no room for error. These items may be too costly or difficult to attain in a production environment.

In general, it is best to order plate with the desired properties (yield point, percent reduction of area, V-notch, and temperature) in its fd precipitation-hardened condition from the mill.

Future plans

In May 1986 we were advised that MarAd funds would no longer be available. We have revised our estimate to perform Phsse 3 from $70000 to $51000 of SP-7 funds available from canceled or completed projects with a December completion. Our goal will be to prove that A71O modified chemistry plate with a minimum 100 ksi yield point through 3 in. thickness can be successfully welded without sustained preheat and no heat input limitations.

We have the material on hand through 53/4 in. thickness; it took almost one year's time to procure this.

We were unable to fmd a U.S. producer willing to make anything less than 100 tone of modified-chemistry 100-kei yield point material, therefore, a foreign producer filled the gap. The 22 tons were delivered in two lots, one costing 52 cents/lb and the other 58 cents/lb.

A comparison of the modified -Chemistry plate is given in Table 3 and the mechanical properties for material over 2 in. thick in Table 4.

Completion of Phases 4A and 4B is dependent on additional funds becoming available. It is strongly believed that this work needs to be done. The potential savings that can be realized are enormous. Beaumont is unable to carry on without MarAd support. We can supply 100-kei yield point plate in 3s/4 in., 411/4 in., 4% in., 511/2 in., and 5s[d in. thickness to whomever MarAd selects to finish the job.

Benefits and potential savings

1. The savings outlined in the May 16, 1986 issue of Iron Age [1] are factual. Specification and use of A71O or ita modification will make them a reality.
2. Increased weld metal "in place" per man-hour. Possible doubling of the "in place" metal with sub-arc. As much as 50 percent more for out-of-position manual welding.
3. Decreased schedule time and shorter delivery times.
4. Decreased weMing wire costs.
5. Fewer welding repaira.

When A71O or its modification replaces a lower-strength material, the following savings will accrue, as a reduction in material thickness will be realized

6. The use of lighter material decreases the deadweight of the unit, thereby increasing its payload or reducing the power requirements to propel it.

Table 1 Panel Sp-7 study goals

Phase	Goal and Plate Thickness	Scheduled cost	Time
1	80 ksi YP through 3 in.	$95000	1 year
2	75 ksi YP through 5 in. 70 ksi through 6 in.	$75000	9 months
3	100 ksi YP through 3 in.	$70000	6 months
4A	90 ksi YP through 5 in. 85 YP through 6 in.	$100000	1 year
4B	Publish results	$50000	9 months
Totals		$390000	4 years

Table 2 Phase 1 and 2 results

PHASE I RESULTS
ALL CHARPY 'V-S ARE TRANSVERSE

THICKNESS	PROCESS	KJ/IN INPUT	Y.P. KSI	T.S.	%	% RA	W	F	1 M/M	3 M/M	5 M/M
PRECIPITATION HARDEN AT 1050°F FOR 165 MIN. AFTER WELDING — CHARPYS AT -8O*F											
2-3/4	DC & AC SAW	208	87.2	107	22	63	9	8	30	41	22
2-3/4	"	. 175	89.2	108	22	58	11	10	64	27	20
P/H AT 1100°F FOR 165 MIN. AFTER WELDING, CHARPYS AT -40°F											
2-1/4	DC&AC	135	93.2	108	26	69	23	98	63	103	103
2-1/4	VERT-STICK	65	S9.6	100	26	72	15	173	136	151	117
P/H AT 1050° F FOR 165 MIN. AFTER WELDING. CHARPYS AT -40DF											
2-3/4	DC5:wAC	150	91.1	107	26	67	3[	51	53	4s	43
2-3/4	"	125	87.9	107	24	66	28	46	52	48	43
2-3/4	n	100	93.2	107	26	67	43	58	77	38	32
2-3/4	DC ONLY	75	94.3	106	26	6S	29	15	46	33	29
P/H AT 1050°F FOR 165 MIN. PRIOR TO WELDING. CHARPYS AT -40*F											
2-3/4	DCS:WAC	1OO	97.6	109	24	67	76	54	50	80	103
2-3/4	"	150	88	108	24	69	78	109	74	64	102
3	"	200	84.7	106	23	67	4094		88	95	56
3	DC ONLY	75	94.7	106	24	67	74	S6	52	72	91
3	DC & AC	125	89.7	107	24	63	8696		76	64	94
3	OC N.G.	75	93.4	106	25	66	61	68	112	73	67
2-3/4	VERT. MIG.	9S	88.7	102	23	58	79	NO	109	93	69

PHASE 11 RESULTS
ALL CHARPY 'V'S ARE TRANSVERSE

P/H AT NOO°F FOR 135 MINS. PRIOR TO WELDING

THICKNESS	PROCESS	KJ/IN INPUT	Y.P. KSI	T.s. KsI	W	CH~P&S AT -40°F M	5 m/M
4	DCs:wAC	192	84	99	30	86	94
4	VERT. MIG.	55	87	100	84	83	82
4-1/2	SAW - NG	73	78.1	90	71	.8	134
4-1/2	VERT - STICK	55	79.6	90	33	112	117
4-1/2	VERT. MIG.	73	76.5	88	59	160	129
5	0C5:wAC	140	7a.4	S6	37-	132	131
5	SAW - NG	75	79.4	90	87	135	172
6	DC5&wAC	130	SO.9	9s	64	77	59
6	SAW - NG	75	S4.6	92.7	51	71	89

7. Lighter material increases the length or width of plates ordered from the mill. This in turn reduces the number of butts or seams required in the unit's design. Therefore, welding requirements are further reduced.

8. Thinner higher-strength plates of greater surface area to construct a unit will reduce plate handling times at the site. Incoming freight bills will decrease as less tonnage is delivered by the carrier.

In addition to the above, less time and effort will be expended by architects and designers in producing the most economical product.

References

1 Irving, R. R., "A Cost-Effective Replacement for HY-80?" *Iron Age*, May 16, 1986.

2 Kvidahl, L. G., "An Improved High Yield Strength Steel for Shipbuilding," *Welding Journal*, July, 1985.

Metric Conversion Factors

1 ft = 0.3048 m
1 in. = 25.4 mm
1 lb = 0.45 kg
1 kJ = 0.948 Btu
1 ksi = 6.9 MPa
°C = (°F − 32) × 5/9

Table 3 Modified-chemistry plate comparison

	A710 Grade A Class 3	A710 Grade A Modified
C	0.07	0.07
Mn	0.40–0.70	1.20–1.70
P	0.025	0.025
S	0.025	0.025
Si	0.40	0.40
Ni	0.70–1.00	0.70–1.00
Cr	0.60–0.90	0.10–0.50
Mo	0.15–0.25	0.20–0.50
Cu	1.00–1.30	1.00–1.35
Cb	0.02	0.02
Al	N/A	0.015–0.65
B	N/A	T

Table 4 Mechanical properties for material over 2 in.

TS min	75 ksi	125 ksi
YP min	65 ksi	100 ksi
% E min	20	20
% RA "Z"	N/A	25
"V" ft/lb °F "L"	50 @ −80°	
"V" ft/lb ABS – FQ70 @ −76°F MODU 1985 Table B.2		30 L 20 T

Discussion

A. D. Wilson, E. G. Hamburg, and J. H. Bucher, Lukens Steel Company

The information reported by Mr. West is of great interest to us because of our similar alloy-development efforts. During the past year, we have also evaluated a "modified" A710 chemistry in order to extend the strength and toughness limits particularly for thicker plates. The chemistry that we have explored is given in Table 5 here with, which compares the range for ASTM A710 Grade A and the typical chemistry of our production heats of HSLA-80 (A710A-3, MIL-S-24645). All of our A710-type steels are produced with low-sulfur, calcium treatment practices and are vacuum degassed. Although the copper and nickel levels are slightly higher than typical, the significant changes in our modified chemistry are the manganese (1.45 percent) and molybdenum (0.45 percent) levels, which were made to increase the hardenability. The levels of these increases are similar to those reported by Mr. West; however, our chromium content remained at about 0.70 percent and no boron was added.

Table 5 Chemistry (weight percent) of select A710 modified-chemistry steels

	Typical Lukens HSLA-80 A710A-3	Lukens Modified A710	ASTM A710 Grade A
C	0.06	0.06	0.07 max
Mn	0.55	1.45	0.40–0.70
P	0.007	0.012	0.025 max
S	0.003	0.002	0.025 max
Cu	1.10	1.25	1.00–1.30
Ni	0.85	0.97	0.70–1.00
Cr	0.70	0.72	0.60–0.90
Mo	0.20	0.45	0.15–0.25
Si	0.30	0.35	0.40 max
Cb	0.035	0.040	0.020 min

Plates from 0.5 to 8 in. in thickness were rolled from an ingot cast heat. The 0.5, 1, and 2-in. plates were heat-treated by austenitizing at 1660°F, water-quenching, and aging between 1120 and 1160°F. The 4, 6, and 8-in. plates were twice austenitized at 1660°F and water-quenched, prior to aging at 1140°F. The results of the tensile and Charpy V-notch (CVN) testing are shown in Table 6 and graphically summarized in Fig. 4. It is apparent that 100-ksi minimum yield strength can be met through 8 in. The microstructures of these plates are principally bainitic in all thicknesses as shown in Fig. 5. As the plate thickness increased, there was the expected increase in grain size and decreased toughness.

Lee G. Kvidahl, Ingalls Shipbuilding

The benefits of a modified-chemistry, high-strength, low-alloy steel are many. Ingalls Shipbuilding has fabricated several thousand tons of this type of material during the construction of U.S. Navy ships and offshore drilling platforms. Based upon this experience, concurrence is offered with Mr. West's basic position that use of this type of material will reduce costs.

The development of these high-strength steels in the thicknesses described in this paper h[illegible] the potential for major reductions in costs for drilling pl[illegible] construction. Ship fabrication does not require the same thickness in plates as the large jack-up platforms. The ability to weld the heavy plates without a sustained preheat and not risk a propensity for cracking provides the fabricator an opportunity to use more cost-effective joining methods. The excellent weldability and fabricability of these materials reduce rework and the associated costs of repairs and increased inspections.

A limiting factor in the use of this type of material could

Table 6 Mechanical properties of A710 modified steel (optimum heat treatment)

Thickness in.	YS, ksi	UTS, ksi	Orientation	CVN (ft-lb), avg/min 0°F	−50°F	−120°F
½	117	121	L	140/135	116/102	82/62
			T	116/96	82/66	62/35
1	110	117	L	166/137	152/128	103/84
			T	136/126	113/97	72/58
2	104	117	L	110/97	91/85	69/54
			T	111/98	85/77	61/39
4	94	106	L	107/93	76/54	42/8
			T	94/83	79/75	18/8
6	88	99	L	117/112	89/69	16/8
			T	86/78	53/8	20/4
8	87	99	L	97/51	79/63	10/3
			T	98/79	72/55	9/4

YS = average yield strength.
UTS = average ultimate yield strength.

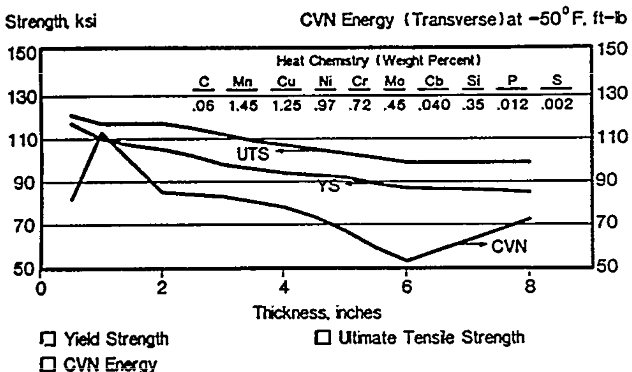

Fig. 4 Mechanical properties of an A710 modified, quenched and aged (1120–1160°F) steel

be the welding materials. Although not specifically addressed in the paper, a review of the test data seems to indicate that the weld material impact properties may not be as tough as the base material. The experience gained by Navy research work and shipyard producibility studies have demonstrated similar results. For this reason, specifications have been developed that define limits on process parameters due to filler material properties instead of base material properties.

To fully utilize the advantages of this type of steel, it is suggested that research work be accelerated in the development of improved filler materials that would provide compatible properties for the full range of applications.

David Y. Ku, American Bureau of Shipping

In accordance with ASTM supplementary requirements for A710 Grade A Class 3, the CVN impact values shall meet an average minimum value of 50 ft-lb (69 J) at −80°F (−62°C) for longitudinal specimens, if specified in the order. However, a review of Phase 1 test results at −80°F (transverse) indicates that some of the CVN values of the weldment may not meet this requirement. Therefore, can it be said that this material can be welded without sustained preheat and almost unlimited heat input as indicated in the abstract?

The A710 type steels obviously have attractive features for offshore and ship applications. However, high toughness levels and excellent weldability are also achievable with the lower-cost thermomechanically controlled processed steels. Would the author care to comment on the relative merits of the two different approaches?

Fig. 5 Typical microstructures for modified A710 plates (*top*) 1 in. thick, (*bottom*) 8 in. thick; nital-pical etchant, ×375

Table 7 Tensile properties of 1.25-inch-thick A710 Grade A plate with various heat treatments[a]

Heat Treatment	Lower Yield Point,[b] ksi	Ultimate Tensile Strength, ksi	Elongation in 1 in., %	Reduction of Area %
Q Water-quenched from 1650°F	73.6	98.9	29	79
Q&PH Q and Harden @ 1100°F for 30 min	93.1	104.8	28	78
Q&S&PH Q and Strain 12% and Harden @ 1100°F for 30 min	102.0	109.9	26	77

[a]0.250-in.-diameter by $1^1/_4$-in. parallel section machined from $^1/_4$T.
[b]0.2% offset yield strength rather than yield point.

George E. Kampschaefer, K & L Associates

This is a most timely paper in view of the fact that the ASTM A710 Grade A Class 3 type steel evaluated has now been adopted by the U.S. Navy as a HSLA-80 grade with slight refinements that will be used selectively in place of HY-80 in order to save material and fabrication costs [3] (additional references follow this discussion). Also, the finding that this alloy steel has the capacity for higher heat inputs in welding without significant loss of notch toughness means lower production welding costs for marine-type constructions, where thicker platings are required that have significant levels of notch toughness. These findings and experiences confirm the results of extensive welding research tests which Jesseman and Schmid reported at the 1983 Annual AWS convention in Philadelphia [4]. Their work suggested that heat inputs up to 125 kJ/in. could be used for welding plates $2^1/_4$ in. thick without significant effects on the HAZ microstructures and toughness. Also, these tests suggested that high heat-input procedures, combined with essentially no preheat, interpass, or post-heat temperature control requirements, make the alloy an ideal material for reducing weld fabrication costs.

Mr. West's paper alludes to another very important characteristic of the A710 alloy steel that should be expanded upon. This concerns the cold-forming capabilities which the A710 alloy provides. Approximately 3500 tons of $1^1/_4$-in.-thick A710 Grade A Class 3 plates were successfully cold-formed to an outside radius of $7^1/_2$ in. for use as chord members for lattice-type legs for Friede & Goldman's L-780 mobile offshore rigs. Approximately 99 percent of these chords were successfully cold-formed without any serious surface cracking problems. This severe cold-working (more than 9 percent outer fiber strain) did not adversely lower the Charpy V-notch toughness below the ABS requirements at −40°F, as established by actual tests conducted on the cold-formed plates. ABS at that time limited cold forming to 3 percent maximum, without test data, to prove the material had not lost its minimum specified toughness.

For the Bethlehem application, the A710 Grade A plates were formed in the as-quenched condition where the yield strength is lower and consequently easier to form; and after forming, the plates were precipitation hardened to 1000°F, which increased the yield strength to the required minimum value. This characteristic of precipitation-hardened (PH) steels lends itself to easier cold-forming of thicker plating or the use of sharper radii for formed sections. In addition, the A710 Grade A alloy can benefit from cold-forming prior to its PH heat treatment and actually provide a higher increase in yield strength without any loss in notch toughness. I do not know of any other construction steel on the market today that responds this favorably to cold-forming! Bethlehem was the first fabricator to take advantage of this benefit and it is a tribute to their aggressive position as a producer of top-quality, economical mobile drilling platforms.

Armco's extensive research on the metallurgical characteristics of the A710 Grade A alloy, as far as cold-straining is concerned, was presented to the Petroleum Division of ASME in 1974 when an industrial group was looking for an X-65 or X-70 steel linepipe for the Canadian Arctic Gas Line [5]. The following data illustrate the unique characteristic of A710. Table 7 gives the tensile properties for the standard Class 3 heat treatment and the PH heat treatments. It should be apparent that the cold-straining has increased the strengthening response of the precipitation-hardening heat treatment by approximately 10 ksi! Figure 6 illustrates the full Charpy V-notch transition curves for the same three treatments and confirms that no significant degradation in transition temperature has occurred as a result of the severe cold forming.

Additional references

3 "High Yield Strength (HSLA-80) Age-Hardenable Alloy Steel Plate, Sheet, or Coil," DOD Specification MIL-S-24645 (SH), Sept. 4, 1984.
4 Jesseman, R. J. and Schmid, G. C., "Submerged Arc Welding a Low Carbon, Copper-Strengthened Alloy Steel," *The Welding Journal*, Nov. 1983, pp. 321-s–330-s.
5 Jesseman, R. J. and Smith, R. C. "Effects of Straining, Aging, and Stress Relieving on Mechanical Properties of Steels for Arctic Service," ASME Paper No. 74-Pet-9.

Author's Closure

The particular steel modification presented and discussed by Messrs. *Wilson, Hamburg,* and *Bucher* is one of several that appears to have the ability to produce a 100-ksi yield-point steel. All of those used to date, such as Armco's modified "Ni-Cop," the Lukens product, Laval University's Professor Krisnadev's work, and the Kawasaki product we are introducing, are of the extra-low carbon, nickel-copper combinations. All are produced with low-sulfur, calcium treatment processes, and precipitation-hardened. All are weldable without sustained preheat and no heat input limitations. Due to the low carbon content of these steels, carbon equivalency calculations can be dispensed with. All have the potential to replace HY-100 at a greatly reduced cost. As has been stated, the Kawasaki steel costs $0.58/lb, delivered in Beaumont.

The discussion of *Mr. Kvidahl* centers, and rightly so, on the fact that the welding materials are somewhat inferior to the base metals. Therefore, the welding materials become a limiting factor in obtaining the maximum cost reduction made possible by the base materials. There is full agreement on this point; the observation that "a chain is only as good as

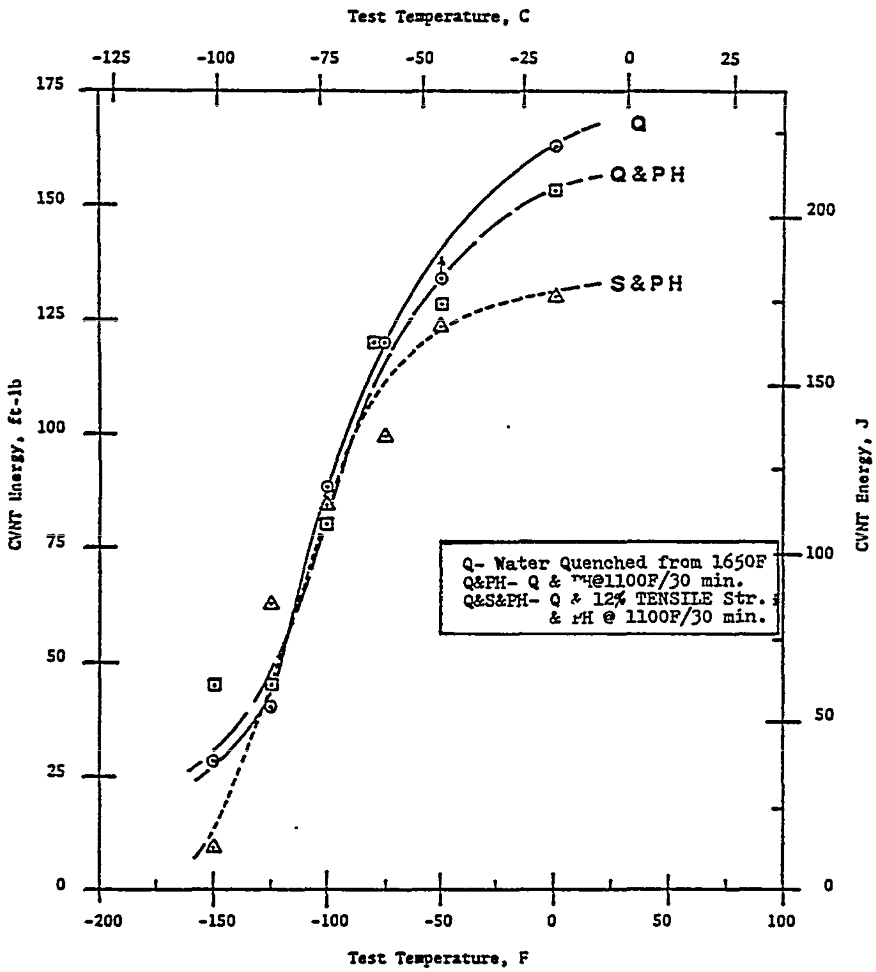

Fig. 6 Charpy V-notch energy curves for ASTM A710 Grade A plate versus heat treatments

its weakest link" is definitely the case in this matter, and accelerated research work is suggested to be directed to this factor. However, it must be realized that our industry is only a very small and declining part of the welding market. Electrode manufacturers and steel producers are volume-profit oriented; therefore, alternating the "status quo" is not one of their strong points.

The discussion of *Mr. Ku* questions the Charpy impact results at −80°F. As was noted, these values were obtained by precipitation hardening after welding. They reinforce the point made by Mr. Kvidahl in that the welding materials are not as good as the plate materials. As shown in the same group of results, the plate itself exhibited satisfactory results. The relative merit of steels produced by the thermomechanically controlled process must be evaluated thusly:

1. What is the on-site delivered cost/pound of the material?
2. What is the yield point, percent *R* of *A* in the "*Z*" direction? What are the CVN values in the weld and heat-affected zones?
3. Will these steels be readily available? Some U.S. producers are dismayed by the huge costs that they must incur to become competitive in the very limited market.
4. What is the in-place cost of fabrication and assembly of these steels? How do they compare with the modified-chemistry steels?

Only this type of analysis will lead to the proper judgment of these types of steels.

Mr. Kampschaefer broached the subject of the cold-forming ability of the modified-chemistry steels. This unusual trait occurs because of the increase in yield strength that is brought about by the precipitation-hardening process; examples of this trait are:

1. A 3-in.-thick A710 Grade A Class 3 plate will have a yield point of about 62 ksi in the quenched-only condition. After precipitation hardening at 1050°F, the yield strength will approach 86 ksi and have a minimum yield point of 80 ksi. Thus, 80/62 = 1.29, which provides a minimum of a 25 percent increase in the forming ability when using existing equipment; a similar percentage decrease in the fabrication costs will result.

2. A 3-in. modified-chemistry plate, as shown, will have a yield point of about 74 ksi in the quenched condition. After precipitation hardening at 1025°F, the yield strength will approach 120 ksi and have a minimum of 100 ksi. Thus, 100/74 = 1.35, which provides a minimum of a 30 percent increase in the forming ability when using existing equipment; a similar percentage decrease in the fabrication costs will result.

In electing to take advantage of these potential cost reductions, it must be remembered that the precipitation hardening still must be done. It is imperative that adequate equipment and facilities be either on hand, procured, or built to accomplish this task, which is normally done by the steel producer.

Cold-forming using these materials needs much more exploration. The potential is beyond imagination. The savings to be realized in other industries such as mining, steel structures, bridges, refinery, and chemical operations need to be pursued. We at Beaumont are proud to have been a pioneer in this effort. We know that it works.

When first proposed, this project was to extend, in four phases, over a four-year period. The results of Phases 1 and 2 have been detailed in this presentation. Plans have also been outlined for Phases 3, 4A, and 4B, provided funds become available.

In the last part of Phase 4 (B), we would show that steels using extra-low-carbon (0.07 and down) combined with various nickel-copper combination additives could be produced to almost any yield point desired, while maintaining notch toughness. These yields, and other properties, would be attained by variations in the precipitation-hardening soak times and temperatures.

Then we would advocate using these products to replace all other steel plates, running the gamut from ASTM A514, 517, and 709 down through the 50- to 65-ksi yield point level (A572, 588, and 633). The savings by eliminating preheat and heat input limitations while welding are beyond comprehension. Replacing basic steels, such as ABS ordinary Grades A, B, CS, D, DS and ASTM .+36 with a 50-ksi yield point nickel-copper would produce measurable material and labor savings. Less weight and less welding time required to complete an item would also reduce scheduled time to produce the same item.

We realize that some of these products have a very limited use in oux industry. However, by showing users (architects, engineers, fabricators, and erectors) in other steel industry segmenk the merits of these products and the potential savings possible, broader markets for these products would develop. Such a move would benefit not only shipbuilding but the rest of the steel industry, including state-side producers, as well.